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Research Paper

Cortisol awakening response and autobiographical memory in healthy older adults: The moderating role of negative reminiscence

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ABSTRACT

The Hypothalamic-Pituitary-Adrenal (HPA) axis's response to stress, with cortisol as a key hormone, has an important impact on cognitive function. Specifically, the Cortisol Awakening Response (CAR), an index of HPA axis functioning, has been linked to declarative memory performance. Autobiographical Memory (AM), a specific form of declarative memory, becomes especially relevant in aging due to its relationship with identity, emotional regulation, and cognitive functioning. However, engaging with the autobiographical past can become maladaptive when it is dominated by negative, self-critical reflections, a pattern referred to as negative reminiscence. This study aimed to examine whether the CAR and negative reminiscence independently predict the specificity of personal memories in healthy older adults, and whether their interaction further explains variability in AM specificity. A sample of 150 healthy older adults (aged 56–81) provided eight saliva samples over two consecutive days to assess the CAR, and they completed standardized measures of AM and reminiscence. Our results showed no significant direct associations between the CAR or negative reminiscence and AM specificity. However, moderation analyses revealed that the CAR significantly predicted a greater tendency to retrieve overgeneral memories, that is, less specific autobiographical memories, but only among individuals with higher negative reminiscence. These results suggest that the way individuals relate to their past plays a key role in the impact of physiological stress on autobiographical recall. The findings underscore the importance of considering both biological and emotional factors to better understand AM in aging.

1. Introduction

Stress affects numerous cognitive functions through the action of cortisol, the end product of the activation of the Hypothalamic-Pituitary-Adrenal axis (HPA-axis). This glucocorticoid hormone follows a circadian rhythm, rising gradually during the latter part of the night and peaking 30–45 min after awakening, a phenomenon known as the Cortisol Awakening Response (CAR) [1,2]. Although its exact function remains unclear, the CAR has been proposed as the body's preparation for the cognitive and emotional demands of the day [3].

In their review, Law and Clow [4] concluded that the association between the CAR and cognition is domain-specific rather than uniform. For prefrontal-dependent functions, positive associations have been observed for executive control [5], whereas results for working memory are inconsistent, with null findings in some studies [6–8] and a positive association reported only in men by Almela et al. [9]. In hippocampal-dependent domains, the evidence is also mixed: Ennis et al. [6] found a positive association with episodic memory, Evans et al. [5] reported null results in declarative memory, and other studies documented negative associations, with higher CAR predicting poorer declarative or episodic memory performance [8,9]. Beyond these domains, null associations have been reported for visuospatial [7], processing speed [6], and global cognitive measures [10], while some studies suggest a non-linear, inverted U-shaped pattern [11]. Taken together, these findings indicate that the effects of the CAR cannot be interpreted in terms of cognition as a whole, but vary across domains, underscoring the importance of domain-specific approaches when examining its role in cognitive functioning.

One such domain is memory, a complex cognitive function typically classified according to the level of conscious awareness involved in recall, distinguishing between declarative and non-declarative memory [12]. Declarative memory includes semantic memory, which involves

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general knowledge, and episodic memory, which is related to personal events and experiences [13], with the latter being particularly dependent on hippocampal integrity. This structure is highly susceptible to chronic stress, which can cause neuronal atrophy, reduced cell density, and inhibited neurogenesis, especially in the dentate gyrus [14]. Importantly, aging affects these memory types differently. Whereas semantic memory tends to remain relatively preserved in normal aging [15], episodic memory typically begins to decline around the age of 60 [16]. In contrast, pathological aging, as in dementia, usually leads to deficits in both types of declarative memory [17]. Interestingly, memories rooted in personal experience appear to be more resilient than impersonal information. For example, individuals with semantic dementia often recall familiar names and visited locations better than names of public figures or unknown places [18], suggesting that personal content remains relatively preserved even in the presence of cognitive decline [15].

The retrieval of personal information, called Autobiographical Memory (AM), refers to the ability to recall personal and subjective experiences from one's life history [19]. AM represents a distinct and dynamic subtype of declarative memory, integrating both episodic and semantic elements [20]. AM recollections are commonly categorized based on their level of specificity [21], typically distinguishing between specific memories –anchored to a particular time and place— and overgeneral memories, characterized by a lack of contextual detail [22]. Beyond simple recall, AM plays a key role in various psychological domains. It provides valuable insights into well-being [23], cognitive status [24], identity development [25], and emotional regulation [26]. In normal aging, AM remains relatively preserved until around the age of 60, after which the episodic component shows a progressive decline [16,27,28].

The hippocampus plays a crucial role in declarative memory and, consequently, in AM. In fact, reduced hippocampal activity has been linked to lower specificity and diminished detail in the recollection of past events [29]. Along with the hippocampus, other regions rich in glucocorticoid receptors, such as the left lateral prefrontal cortex and the amygdala, are involved in the retrieval of emotional autobiographical content [30], reinforcing the link between stress and memory [31]. In this regard, cortisol can disrupt functional connectivity between the hippocampus and amygdala during emotional processing, and it can also interfere with intrinsic networks involving the prefrontal and extrastriate cortices [32], potentially impairing the retrieval of detailed and coherent AM. Within the prefrontal cortex, the medial region is a central hub of the Default Mode Network (DMN), a system involved in self-referential thoughts, rumination, and AM retrieval [33], which is particularly vulnerable to stress-induced dysregulation. Experimental evidence shows that stress impairs DMN-related functioning, leading to AM difficulties [34]. Moreover, prefrontal cortex damage has been associated with reduced AM specificity [35], and age-related declines in episodic detail have been linked to both structural and functional changes in this region [36].

Upon awakening, the brain initiates booting-like cognitive processes that reactivate both stable self-related representations, such as personality and identity, and temporary traces from recent experiences [37]. This function supports the idea that the CAR, beyond preparing the body for daily cognitive demands, as previously mentioned, also contributes to self-related processing and engagement with one's personal history [3]. In line with this, the CAR has been associated with emotional regulation, and it may serve to counter-regulate emotional experiences from the previous day, particularly in individuals prone to rumination and chronic stress [38–40]. Moreover, not all individuals engage with their autobiographical past in the same way. Reminiscence Theory and Life Story Approaches [41] have explored the functional motives for remembering, especially in aging, when the need to find coherence and meaning in lived experiences becomes more prominent. This reflective process and its associated subjective mechanisms have been described as the "inside of aging" [42]. However, when reminiscence is dominated by negative reflections, it may resemble rumination, a persistent, repetitive pattern of negative, self-focused thinking about past experiences, often lacking variation in purpose [38]. When this ruminative pattern becomes integrated into autobiographical recall, it reflects a maladaptive reminiscence function, where individuals become fixated on negative aspects of their past [43]. These maladaptive cognitive styles, frequently linked to DMN activity, may sustain stress and, consequently, impair cognitive function. Such patterns have been associated with reduced AM specificity and a greater tendency to retrieve overgeneral memories [44].

With all this in mind, the main purpose of this study was to investigate how the CAR and negative reminiscence are related to AM specificity in healthy older adults. To address this topic, we first explored the relationships independently, separately focusing on the potential associations of the CAR and negative reminiscence with AM specificity. Given that previous findings on the CAR–cognition link have been mixed in declarative memory [5,6,8,9], we can not establish a specific direction of this association. Anyway, we expected that higher levels of negative reminiscence would be associated with a greater tendency to retrieve overgeneral memories. This proposal is based on evidence suggesting that negative reminiscence reflects a maladaptive, ruminative cognitive style [43] associated with increased stress and overgeneral retrieval patterns [38,44]. Thus, we examined whether negative reminiscence moderates the relationship between the CAR and AM specificity. In this line, we posited that this association would be positively moderated by negative reminiscence, which is consistent with findings showing that maladaptive reminiscence functions can exacerbate both cognitive and emotional difficulties [45].

2. Material and methods

2.1. Participants

For this study, 150 healthy older adults (71 male and 79 female) from 56 to 81 years old (Mean = 67.14 SD = 32.24) were recruited from a university program for people over 55 years of age at the University of Valencia. As compensation for their participation in the study, they received a pen drive and a report on their neuropsychological performance. Exclusion criteria were: smoking >10 cigarettes per day, alcohol or drug abuse, visual or hearing difficulties, neurological or psychiatric disease, diabetes, medication that may affect hormonal levels or cognitive function, such as psychotropic substances or sleep medication, having been under anesthesia in the past 12 months, and having experienced serious stressful events in the past year, such as the death of a relative, an accident, or a drastic change in their habits. Additionally, all the women had been postmenopausal for at least 3 years, and they were not receiving hormonal therapy. Furthermore, all the participants obtained a score of at least 27 on the Mini-Mental State Examination (MMSE) [46] to corroborate that they did not present cognitive impairment. Participants reported a Body Mass Index (BMI) of between 16.89 and 38.93 and a medium-high socioeconomic status (SES). SES was measured with the nine-rung social ladder [47]. The ladder represented nine rungs on which the participants were asked to place themselves. The highest rungs represented the highest socioeconomic status in our country, that is, a lot of money, a good education, and the best jobs. In contrast, the lowest rungs represented the poorest people, that is, less education and worse jobs or no job. Additionally, participants completed the Beck Depression Inventory (BDI; [48]) and the Trait subscale of the State–Trait Anxiety Inventory (STAI-T; [49]) to assess subclinical depressive and anxiety symptoms. On average, the sample reported low levels of depressive and trait anxiety symptoms, with no participant reaching the clinical cut-off scores for major depression or severe anxiety (see Table 1).

The study was carried out according to the Declaration of Helsinki. The Ethics Committee of the University of Valencia approved the protocol (Code: 1034,878). All participants received verbal and written

Table 1
Data presented for the total sample and for men and women separately.

	Total sampleN=150	MenN=71	WomenN=79	*t* (*p*)
Age (years)	66.87 (5.16)	67.67 (4.66)	66.16 (5.49)	1.81 (0.07)
BMI (Kg/m2)	26.98 (3.76)	27.58 (3.18)	26.44 (4.17)	1.83 (0.07)
SES	5.65 (1.26)	5.79 (1.34)	5.52 (1.18)	1.29 (0.20)
Depression (BDI)	4.85 (4.09)	4.61 (3.91)	5.03 (4.27)	−0.63 (0.53)
Anxiety (STAI)	15.96 (7.49)	14.86 (7.5)	16.73 (7.21)	−1.56 (0.12)
CAR	0.43 (0.49)	0.34 (0.45)	0.52 (0.51)	−2.12 (0.04)
Negative Reminiscence AM	35.34 (10.77)	34.86 (10.44)	35.79 (11.17)	−0.53 (0.60)
Specific memories	6.38 (3.21)	6.83 (3.34)	6.01 (3.08)	1.44 (0.15)
Overgeneral memories	2.96 (1.69)	2.92 (1.75)	2.99 (1.66)	−0.26 (0.80)
Omissions	3.77 (2.63)	3.63 (2.86)	3.89 (2.44)	−0.54 (0.59)

Data represent means (standard errors), t(p) are presented for the differences between men and women. BMI: Body Mass Index; SES: Socioeconomic Status Scale; CAR: Cortisol Awakening Response; AM: Autobiographical Memory.

information about the study and signed an informed consent.

2.2. Procedure

Participants who met the criteria were asked to attend a laboratory at the Faculty of Psychology, and they were given detailed written instructions for collecting cortisol samples at home by themselves. They were asked to provide a total of 4 saliva samples on two consecutive weekdays using salivettes (Sarstedt, Nümbrecht, Germany). These saliva samples were collected at home immediately after awakening, 15-, 30-, and 45-min post-awakening. Moreover, participants were instructed to follow their usual sleep pattern, avoid strenuous exercise on those days, drink only water, not eat 2 h before each sample collection, and not brush their teeth in the same period of time (for more details see: [50]). In order to ensure the sample collection times, the cotton from the salivettes was stored in MEMS TrackCap Containers (MEM 6 TrackCap Monitor, Aardex Ltd., Switzerland). The time of each sample collection was recorded in a log by the participants. When participants delivered the saliva samples to the laboratory, they completed a sociodemographic questionnaire and the psychological tests, including the Autobiographical Memory Test, all administered within a controlled time window (between 16:00–18:00 h) to minimize potential variability due to diurnal cortisol fluctuations.

2.3. Instruments

2.3.1. Autobiographical memory test (AMT)

The Spanish adaptation [51] of the AMT [52] was used to measure the ability to recall specific memories about their own lives in response to a cue word. The test consists of 15 Spanish words used as cue words. Five words were classified as positive (funny, lucky, passionate, happy, and hopeful), five as negative (unsuccessful, unhappy, sad, abandoned, and gloomy), and five as neutral (work, city, home, shoes, and family). Following the test instructions, positive, negative, and neutral cue words were presented alternatively. The experimenter presented the cue words to the participants with the instruction to try to recall a specific memory after hearing each word. Previously, they had been told that a specific memory was a detailed recall of an event lasting no longer than 24 h, and examples were provided (i.e., I felt really happy the day of my son's birth in the hospital). For the positive and negative cue words, the form used was "*Try to remember a day or situation in the past when you felt [cue word]. Can you describe it?*". For neutral cue words, the form was "*Try to remember a special day about [cue word]*" [51]. The cue words were presented orally, and the session was voice-recorded for later evaluation. If participants were not able to recall a memory in 30 s, it was considered an omission, and the next word was presented. The evaluation of the memories focused on one main characteristic: their specificity. Memories were classified as specific (consisting of an event with several details lasting <24 h), overgeneral (those that did not meet these characteristics regarding details and duration), or omissions. Two judges with no previous contact with the participants were trained to analyze the AMT responses. In the present study, the interrater agreement was as follows: specific memories (ICC = 0.905) and overgeneral memories (ICC = 0.752).

2.3.2. Reminiscence function scale (RFS)

We employed the Spanish adaptation [53] of the RFS [54]. On this questionnaire, participants indicate how frequently they reminisce for different reasons, using a Likert-type scale from 6 (very frequently) to 0 (never). All the items are presented using the form: "*I remember the past when/because…*". For the purposes of the present study, only the Self-Negative function was employed. This factor captures a maladaptive and ruminative pattern of reminiscence often associated with lower psychological well-being (e.g., boredom reduction, intimacy maintenance, and bitterness revival). Internal consistency for this subscale was high (Cronbach's $\alpha = 0.90$).

2.4. Cortisol analyses

Saliva samples were collected by using salivettes (Sarstedt, Numbrecht, Germany). Following written instructions, participants kept a cotton swab in their mouth for 2 min without chewing it while moving it in a circular pattern to collect saliva from all the different salivary glands. Samples were kept in a refrigerator until they were delivered to the laboratory.

When the samples arrived at the laboratory, they were kept in the refrigerator until they were centrifuged (4000 rpm for 15 min). After the centrifugation, the samples resulted in a clear floating of low viscosity to be stored at −80 °C for posterior analysis. These analyses were performed in duplicate with the salivary cortisol ELISA kit by Salimetrics (Newmarket, UK). Assay sensitivity was >0.007 ug/dL. Inter- and intra-assay variation coefficients were all below 8 %. Cortisol levels were expressed in nmol/L.

2.5. Statistical analysis

To assess normal distribution and homogeneity of variance, Kolmogorov–Smirnov and Levene's test were performed. Because the cortisol values were not normally distributed, raw cortisol data were logarithm 10 (Log10) transformed. The CAR was calculated as the area under the curve with respect to the increase (see [55]) from the saliva samples taken 0-, 15-, 30, and 45- min after awakening (Fig. 1).

Consistent with previous literature, the correlation between Day 1 and Day 2 CAR was significant but modest ($r = 0.248$, $p < 0.01$), which is expected given the strong situational influences on single-day assessments. Following methodological recommendations guidelines, we therefore averaged CAR across the two days to derive a more reliable, trait-like estimate of basal HPA activity [3,56–58].

All the statistical analyses were conducted using R (version 4.4.2). To examine the first and more exploratory objective, namely, the independent associations between the CAR, negative reminiscence, and AM (i.e., specific memories, overgeneral memories, and omissions), we performed partial correlation analyses using the ppcor package. These analyses were controlled for age, sex (numerically coded only for this analysis), SES, BMI and awakening time. Additionally, to minimize the risk of residual confounding from undiagnosed or subclinical emotional

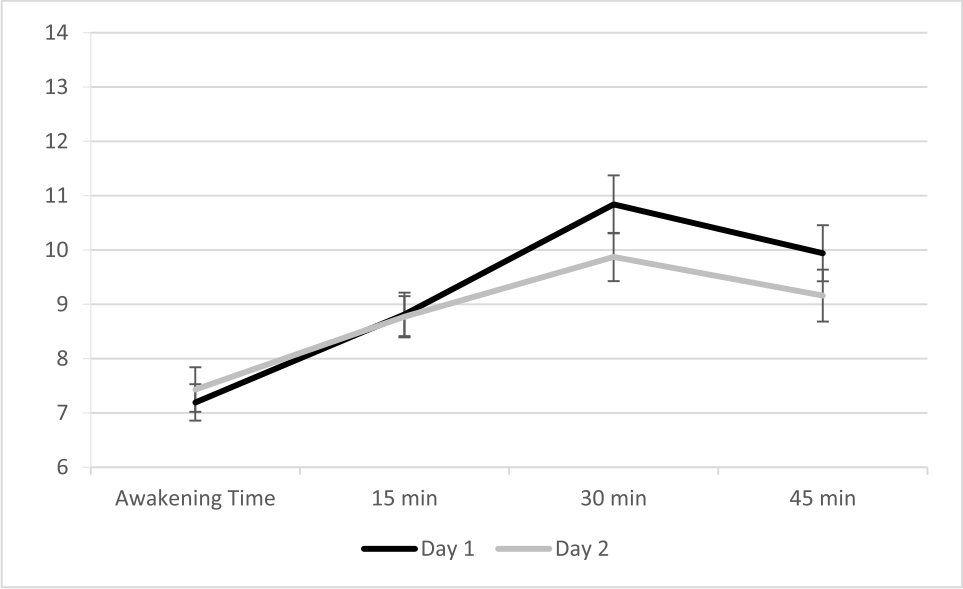

Fig. 1. CAR profile for Days 1 and 2. Depicted values are means, and error bars represent SEM.

problems, we further controlled for depressive and anxiety symptoms.

For the second and main objective (i.e., testing whether the negative reminiscence function moderated the association between the CAR and AM), we ran multiple linear regression models using the lm() function of the stats package in base R. Moderation was assessed by including the interaction term CAR × negative reminiscence. Age, sex, SES, BMI, depression, anxiety and awakening time were included as covariates in all models. Separate models were conducted for each AM outcome.

Interaction effects were further explored using the interactions and ggeffects packages, which allowed us to probe and visualize the conditional effects of the CAR at different levels of negative reminiscence.

Before performing the statistical analyses, missing cortisol data were imputed using the expectation-maximization method in cases where only one sample was left (8), whereas cases with more than one sample left were excluded (10). In addition, there were 10 outliers (one from CAR, two from omissions, and five from neutral memories in AMT; as well as two from negative reminiscence in RSF) defined as values falling more than ±3 standard deviations from the sample mean.

Post hoc statistical power analysis was performed using the pwr package in R, following the recommendations of Perugini et al. [59], who suggest treating moderated regression like any other linear model when computing effect sizes. The analysis was based on a total of 110 participants, six predictors (including the interaction term), an alpha level of 0.05, and a medium effect size ($f^2 = 0.15$). The resulting statistical power was 0.85, which meets the standard threshold of 0.80 recommended for adequate power [60].

3. Results

3.1. CAR, negative reminiscence and AM: partial correlations

Partial correlations did not show significant associations between the CAR or negative reminiscence and any of the AM outcomes (all $p > 0.48$; Table 2).

3.2. Moderation role of negative reminiscence in the relationship between CAR and AM

Moderation analyses showed a significant moderation of negative reminiscence in the CAR and overgeneral memories relationship (R^2=0.18, ΔR^2=0.1, B = 0.12, SE=0.04, $t = 3.33$, $p < 0.01$, CI 95 %= 0.05, 0.2). Specifically, the association between the CAR and overgeneral memories was positive for people who scored high on negative reminiscence (B = 2.07, SE=0.6, $t = 3.42$, $p < 0.01$, CI 95 %=0.87, 3.26) and medium on negative reminiscence (B = 0.77, SE=0.35, t = 2.17, p = 0.03, CI 95 %=0.07, 1.47), but not for those with low scores on this variable (both $p > 0.23$) (see Table 3 and Fig. 2).

Table 2
Partial correlation analysis with CAR, negative reminiscence, and autobiographical memory, controlled for age, sex, SES, IMC, depression, anxiety and awakening time.

	CAR		Negative Reminiscence	
	r	*p*	r	*p*
AM				
Specific memories	−0.02	0.8	0.03	0.76
Overgeneral memories	0.07	0.48	−0.07	0.51
Omissions	−0.01	0.93	−0.04	0.72

AM: Autobiographical Memory.

4. Discussion

This study aimed to investigate whether the specificity of AM in healthy older adults can be predicted by the CAR and negative reminiscence, considering both their individual contributions and their potential interactive effects. Overall, direct associations between the CAR or negative reminiscence and AM specificity were not found. However, the relationship between the CAR and autobiographical recall depended on the levels of negative reminiscence. Specifically, higher CAR levels were associated with greater overgeneral memory retrieval, but only in individuals who tended to engage in more negative reflections about their past.

To the best of our knowledge, no previous study has investigated the relationship between the CAR and AM specificity in healthy older adults. Barry et al. [61] explored this association in an adolescent sample, reporting that higher CAR was linked to greater AM specificity. However, their methodology for computing CAR differed from ours, and the age disparity between the samples is noteworthy. The discrepancy may be explained by the distinct neurocognitive profile associated with age. In later life, changes in neural functioning, particularly in the prefrontal cortex, have been associated with reductions in episodic specificity [36].

Table 3
Negative reminiscence moderation in the relationship between CAR and AM.

	R^2	ΔR^2	B	SE	t	*p*	CI95 %	
CAR*Negative Reminiscence								
Specific Memories	0.03	0.00	−0.02	0.07	−0.03	0.73	−0.17	0.12
Overgeneral Memories	0.18	0.1	0.12	0.04	3.33	<0.01	0.05	0.2
Low			−0.53	0.44	−1.20	0.23	−1.39	0.34
Medium			0.77	0.35	2.17	0.03	0.07	1.47
High			2.07	0.6	3.42	<0.01	0.87	3.26
Omission	0.01	0.00	−0.03	0.06	−0.45	0.65	−0.15	0.09

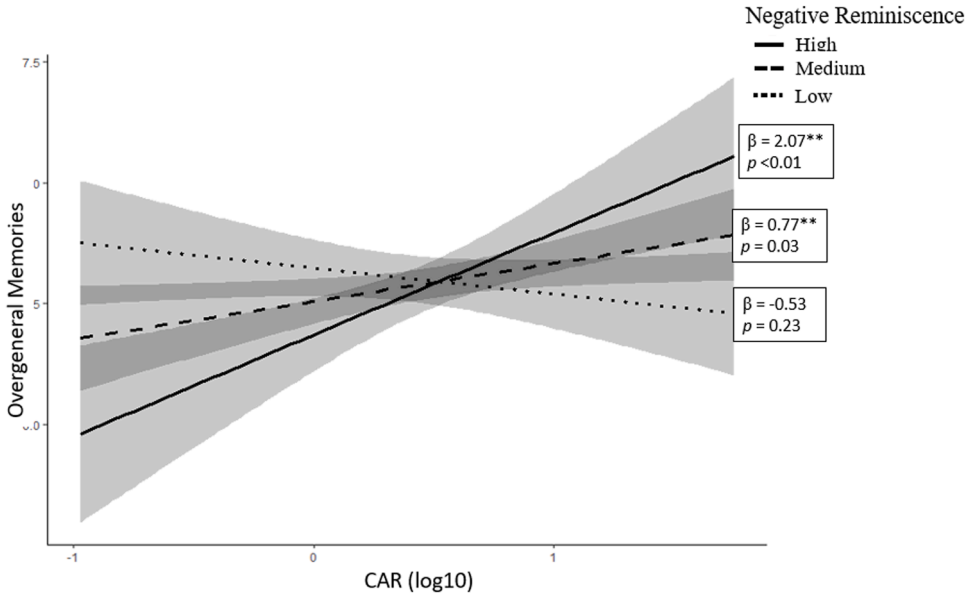

Fig. 2. Moderation of negative reminiscence in the relationship between CAR and AM.

Although the exact neural mechanisms by means of which cortisol affects memory remain unclear [62], current models suggest that cortisol disrupts intrinsic connectivity within the prefrontal cortex and impairs functional communication between the hippocampus and amygdala [32]. These effects are probably due to the high density of glucocorticoid receptors in hippocampal regions [63]. Notably, the hippocampus is not only critical for declarative memory formation [64], but it also plays a central role in the regulation of the CAR [65].

No significant association was found between negative reminiscence and AM specificity. This result suggests that negative reminiscence, when considered independently, may not exert a direct influence on the quality of autobiographical recall in healthy older adults. However, its interaction with physiological stress markers, such as the CAR, appears to be more relevant. Previous literature has described negative reminiscence as a maladaptive and ruminative cognitive style [43] often associated with sustained stress and reduced episodic specificity [38, 44]. These patterns are believed to interfere with DMN functioning [33], a system closely tied to autobiographical retrieval. Thus, although no main relationship was detected, the theoretical framework supports the idea that negative reminiscence may act as a vulnerability factor that amplifies the impact of stress-related physiological processes on AM.

Our main objective was to examine whether the relationship between the CAR and AM specificity was moderated by negative reminiscence. This construct becomes particularly relevant in aging, given that reflecting on one's past contributes to maintaining identity and coherence throughout the life span [42]. To explore this question, we focused on the negative reminiscence function described by Webster [43], which captures a ruminative and emotionally negative engagement with personal memories. However, our moderation analysis showed that the CAR predicted a greater number of overgeneral memories, but only in individuals with higher levels of negative reminiscence. This finding supports our hypothesis that a negative cognitive style when reflecting on the past can amplify the detrimental effects of the CAR on memory performance. It also aligns with previous studies suggesting that an elevated CAR may negatively impact memory domains dependent on hippocampal functioning, such as declarative memory in healthy older people [8,9]. Notably, whereas these earlier studies used standardized neuropsychological tests focused on verbal memory (e.g., the AVLT or the Logical Memory subtest of the WMS-III), our study extended this line of research by assessing AM, an ecologically valid measure of declarative memory that incorporates both episodic and semantic elements through the recall of richly detailed personal events. In this regard, our findings offer a more nuanced and personally relevant view of how stress physiology and maladaptive reminiscence interact to shape memory functioning in aging. However, it is important to note that our study did not include direct assessments of participants' motivation, emotional regulation, or task engagement and the potential influence of these factors on memory performance cannot be entirely ruled out. Therefore, further interpretation of the findings should be approached with appropriate caution.

From a cognitive perspective, AM is a distinct form of declarative memory that stores personally relevant information. According to Conway and Jobson [20], AM is organized hierarchically, with specific memories situated at the top being more detailed and context-bound, and overgeneral memories at the base representing broader, less detailed recollections. From this perspective, retrieving a specific memory requires more cognitive effort than producing an overgeneral one. Our findings suggest that the CAR, as a physiological marker of stress, may be associated with reduced episodic specificity of AM, but only in individuals who habitually engage in negative reminiscence.

This maladaptive style of reflecting on the past has been associated with lower psychological well-being and reduced life satisfaction [53]. In our sample, individuals who scored higher on negative reminiscence appeared to be more vulnerable to the effects of the CAR, showing a greater tendency to retrieve overgeneral memories, an indicator of less effective declarative memory functioning. These findings emphasize the relevance of psychological factors and motivational states in AM performance, highlighting that the relationship between physiological stress (CAR) and AM specificity depends on the way individuals engage with their past.

Although the present study focused on the HPA axis and the CAR as a specific physiological marker, it is worth noting that the HPA axis interacts with other endocrine systems, such as the hypothalamic-pituitary-gonadal (HPG) and hypothalamic-pituitary-thyroid (HPT) axes, through shared regulatory mechanisms at the hypothalamic and pituitary levels [66,67]. Chronic stress-related dysregulation of the HPA axis may also affect these systems, while gonadal and thyroid hormones can, in turn, modulate the stress response [68,69]. Although not the primary focus of the present study, this broader neuroendocrine interplay may help explain individual differences in CAR expression and its links to cognition, and thus represents an important avenue for future research.

Some limitations should be considered when interpreting the present findings. First, although we assessed the specificity of AM, the information reported by the participants about both the memories and their associated reminiscence functions referred to experiences across the entire lifespan, without distinguishing the temporal context in which these memories occurred. In other words, we did not account for the temporal proximity of the recalled events, which could have offered additional insight into the nature of the memory retrieval, as highlighted by Warne et al. [70]. Second, our sample was intentionally homogeneous in terms of the participants' health status in order to reduce variability in endocrine function, particularly regarding cortisol responses. Although this practice enhances internal validity, it limits the generalizability of our findings to more diverse populations, including individuals with physical or psychological conditions. Third, the absence of direct measures of participants' mood, motivation, or task engagement represents a limitation of the present study. Although all participants were healthy volunteers who took part without significant external incentives, implying a presumed baseline level of intrinsic motivation, we acknowledge that these factors were not explicitly assessed using formal self-report or behavioural instruments. As a result, alternative non-cognitive explanations, such as reduced motivation or a tendency to avoid emotionally distressing memories, cannot be fully ruled out. For this reason, the interpretation of our main findings should be approached with caution. Future studies should consider incorporating direct assessments of motivation and emotional regulation to better disentangle cognitive performance from affective or motivational influences.

In conclusion, our findings indicate that negative reminiscence moderates the relationship between the CAR and the tendency to recall overgeneral autobiographical memories, and this becomes stronger in individuals who tend to think negatively about their past. This result highlights the relevance of emotional dimensions in the study of AM, particularly in relation to physiological stress markers such as the CAR. Specifically, our results suggest that the detrimental association between the CAR and declarative memory performance emerges primarily in individuals with a more negative and ruminative style of reflecting on their past. Furthermore, these findings reinforce the notion that certain psychological factors, such as reminiscence style, play a crucial role in modulating the cognitive consequences of stress, especially in later life. Finally, to our knowledge, this is the first study to explore the interaction between the CAR and AM in relation to negative reminiscence specificity, offering a novel psychophysiological perspective on memory functioning in older adults. Nevertheless, reduced motivation or a tendency to avoid emotionally distressing memories should be considered as potential influences and cannot be entirely ruled out.

CRediT authorship contribution statement

Pablo Rivas-Diaz: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Teresa Montoliu:** Supervision, Methodology, Investigation, Data curation, Conceptualization. **Vanesa Hidalgo:** Writing – review & editing, Validation, Supervision, Conceptualization. **Alicia Salvador:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors state that there are no conflicts of interest associated with the research.

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Data availability

Data available on request from the authors.

References

[1] R. O'Hara, C.M. Schröder, R. Mahadevan, A.F. Schatzberg, S. Lindley, S. Fox, M. Weiner, H.C. Kraemer, A. Noda, X. Lin, H.L. Gray, J.F. Hallmayer, Serotonin transporter polymorphism, memory and hippocampal volume in the elderly: association and interaction with cortisol, Mol. Psychiatry 12 (6) (2007) 544–555, https://doi.org/10.1038/sj.mp.4001978.

[2] J.C. Pruessner, O.T. Wolf, D.H. Hellhammer, A. Buske-Kirschbaum, K. Von Auer, S. Jobst, C. Kirschbaum, Free cortisol levels after awakening: a reliable biological marker for the assessment of adrenocortical activity, Life sciences 61 (26) (1997) 2539–2549, https://doi.org/10.1016/S0024-3205(97)01008-4.

[3] T. Stalder, H. Oster, J.L. Abelson, K. Huthsteiner, T. Klucken, A. Clow, The cortisol awakening response: regulation and functional significance, Endocr. Rev 46 (1) (2025) 43–59.

[4] R. Law, A. Clow, Stress, the cortisol awakening response and cognitive function, in: International Review of Neurobiology, 150, Academic Press Inc, 2020, pp. 187–217, https://doi.org/10.1016/bs.irn.2020.01.001.

[5] P. Evans, F. Hucklebridge, C. Loveday, A. Clow, The cortisol awakening response is related to executive function in older age, Int. J. Psychophysiol. 84 (2) (2012) 201–204, https://doi.org/10.1016/j.ijpsycho.2012.02.008.

[6] G.E. Ennis, S.D. Moffat, C. Hertzog, The cortisol awakening response and cognition across the adult lifespan, Brain Cogn. 105 (2016) 66–77, https://doi.org/10.1016/j.bandc.2016.04.001.

[7] C.E. Franz, R.C. O'Brien, R.L. Hauger, S.P. Mendoza, M.S. Panizzon, E. Prom-Wormley, L.J. Eaves, K. Jacobson, M.J. Lyons, S. Lupien, D. Hellhammer, H. Xian, W.S. Kremen, Cross-sectional and 35-year longitudinalassessment of salivary cortisol and cognitive functioning: the Vietnam era twinstudy of aging, Psychoneuroendocrinology 36 (7) (2011) 1040–1052.

[8] V. Hidalgo, M. Almela, M.M. Pulopulos, A. Salvador, Memory performance is related to the cortisol awakening response in older people, but not to the diurnal cortisol slope, Psychoneuroendocrinology 71 (2016) 136–146, https://doi.org/10.1016/j.psyneuen.2016.05.019.

[9] M. Almela, L. van der Meij, V. Hidalgo, C. Villada, A. Salvador, The cortisol awakening response and memory performance in older men and women, Psychoneuroendocrinology 37 (12) (2012) 1929–1940, https://doi.org/10.1016/j.psyneuen.2012.04.009.

[10] R.S. Stawski, D.M. Almeida, M.E. Lachman, P.A. Tun, C.B. Rosnick, T. Seeman, Associations between cognitive function and naturally occurring dailycortisol during middle adulthood: timing is everything, J. Gerontol. B Psychol.Sci. Soc. Sci. (2011), 66B (Suppl. 1), i71–i81.
[11] A.S. Moriarty, A.J. Bradley, K.N. Anderson, S. Watson, P. Gallagher, R. H. McAllister-Williams, Cortisol awakening response and Spatial working memory in man: a U-shaped relationship, Hum. Psychopharmacol. Clin. Exp. 29 (3) (2014) 295–298.
[12] Botelho De Oliveira, S., María, L., Prada, A., Conde Cotes, C.A., Fandiño Franky, J., Alberto, C., & Tomaz, B. (2008). Evaluación de la memoria declarativa asociada con contenido emocional en pacientes lobectomizados. In Revista Latinoamericana de Psicología (Vol. 40, Issue 2).
[13] E. Tulving, Episodic and semantic memory, Organ. mem. (1972), 1(381-403), 1.
[14] E.E. Romero Romero, J. Young, R. Salado-Castillo, Fisiología del estrés y su integración al sistema nervioso y endocrino, Rev. Méd. Cient. 32 (2020) 61–70, https://doi.org/10.37416/rmc.v32i1.535.
[15] B. Levine, E. Svoboda, J.F. Hay, G. Winocur, M. Moscovitch, Aging and autobiographical memory: dissociating episodic from semantic retrieval, Psychol. Aging 17 (4) (2002) 677–689, https://doi.org/10.1037/0882-7974.17.4.677.
[16] P. Piolino, B. Desgranges, K. Benali, F. Eustache, Episodic and semantic remote autobiographical memory in ageing, In Memory 10 (4) (2002) 239–257, https://doi.org/10.1080/09658210143000353.
[17] U. Seidl, U. Lueken, P.A. Thomann, J. Geider, J. Schröder, Autobiographical memory deficits in Alzheimer's disease, J. Alzheimer's Dis. 27 (3) (2011) 567–574, https://doi.org/10.3233/JAD-2011-110014.
[18] Westmacott, R.M. (2001). Temporally-graded retrograde memory loss in semantic dementia, medial temporal lobe amnesia and Alzheimer's dementia, reconciling the hippocampal consolidation and multiple trace theories of long-term memory storage (Doctoral dissertation).
[19] E.G. Schachtel, On memory and childhood amnesia, Psychiatry 10 (1) (1947) 1–26, https://doi.org/10.1080/00332747.1947.11022620.
[20] M.A. Conway, L. Jobson, On the nature of autobiographical memory, Underst. autobiogr. mem.: Theor. approaches (2012) 54–69.
[21] J.C. Meléndez, J. Escudero, E. Satorres, A. Pitarque, Type of memory and emotional valence in healthy aging, mild cognitive impairment, and Alzheimer's disease, Psicothema 31 (1) (2019) 60–65, https://doi.org/10.7334/psicothema2018.181.
[22] M. El Haj, P. Antoine, J.L. Nandrino, D. Kapogiannis, Autobiographical memory decline in Alzheimer's disease, a theoretical and clinical overview, in: In Ageing Research Reviews, 23, Elsevier Ireland Ltd, 2015, pp. 183–192, https://doi.org/10.1016/j.arr.2015.07.001.
[23] Q. Kennedy, M. Mather, L.L. Carstensen, The role of motivation in the age-related positivity effect in autobiographical memory, Psychol. Sci. 15 (3) (2004) 208–214, https://doi.org/10.1111/j.0956-7976.2004.01503011.x.
[24] J.J. Ricarte, J.M. Latorre, L. Ros, B. Navarro, M.J. Aguilar, J.P. Serrano, Overgeneral autobiographical memory effect in older depressed adults, Aging Ment. Health 15 (8) (2011) 1028–1037, https://doi.org/10.1080/13607863.2011.573468.
[25] R. Fivush, T. Habermas, T.E. Waters, W. Zaman, The making of autobiographical memory: intersections of culture, narratives and identity, Int. J. Psychol. 46 (5) (2011) 321–345, https://doi.org/10.1080/00207594.2011.596541.
[26] D. Hermans, A. Defranc, F. Raes, J.M.G. Williams, P. Eelen, Reduced autobiographical memory specificity as an avoidant coping style, Br. J. Clin. Psychol. 44 (4) (2005) 583–589, https://doi.org/10.1348/014466505X53461.
[27] T. Hedden, J.D.E. Gabrieli, Insights into the ageing mind: a view from cognitive neuroscience, in: Nature Reviews Neuroscience, 5, European Association for Cardio-Thoracic Surgery, 2004, pp. 87–96, https://doi.org/10.1038/nrn1323.
[28] L.G. Nilsson, Memory function in normal aging, In Acta Neurol. Scand. Suppl. 107 (179) (2003) 7–13, https://doi.org/10.1034/j.1600-0404.107.s179.5.x.
[29] D.R. Addis, D.L. Schacter, Constructive episodic simulation: Temporal distance and detail of past and future events modulate hippocampal engagement, Hippocampus 18 (2) (2008) 227–237.
[30] R. Cabeza, P. St Jacques, Functional neuroimaging of autobiographical memory, Trends Cogn. Sci. 11 (5) (2007) 219–227.
[31] J. Chen, Z. Wei, H. Han, L. Jin, C. Xu, D. Dong, Z. Peng, An effect of chronic stress on prospective memory via alteration of resting-state hippocampal subregion functional connectivity, Sci. Rep. 9 (1) (2019) 19698.
[32] Y. Hakamata, S. Komi, E. Sato, S. Izawa, S. Mizukami, Y. Moriguchi, H. Tagaya, Cortisol-related hippocampal-extrastriate functional connectivity explains the adverse effect of cortisol on visuospatial retrieval, Psychoneuroendocrinology 109 (2019) 104310.
[33] D.L. Schacter, D.R. Addis, R.L. Buckner, Remembering the past to imagine the future: the prospective brain, Nat. Rev. Neurosci. 8 (9) (2007) 657–661.
[34] M.S. Tollenaar, B.M. Elzinga, P. Spinhoven, W. Everaerd, Immediate and prolonged effects of cortisol, but not propranolol, on memory retrieval in healthy young men, Neurobiol. Learn. Mem. 91 (1) (2009) 23–31.
[35] M.C. McKinnon, K.A. Philp, A.F. Campbell, N. Kovacevic, M. Moscovitch, B. L. Miller, Remote memory deficits in patients with frontotemporal dementia: dissociation of episodic from semantic autobiographical memory, J. Int. Neuropsychol. Soc. 8 (2002) 199.
[36] R. Cabeza, L. Nyberg, Neural bases of learning and memory: functional neuroimaging evidence, Curr. Opin. Neurol. 13 (4) (2000) 415–421.
[37] I. Wilhelm, J. Born, B.M. Kudielka, W. Schlotz, S. Wüst, Is the cortisol awakening rise a response to awakening? Psychoneuroendocrinology 32 (4) (2007) 358–366.
[38] P.M. Zoccola, S.S. Dickerson, S. Lam, Rumination predicts longer sleep onset latency after an acute psychosocial stressor, Biopsychosoc. Sci. Med. 71 (7) (2009) 771–775.
[39] W. Schlotz, J. Hellhammer, P. Schulz, A.A. Stone, Perceived work overload and chronic worrying predict weekend–weekday differences in the cortisol awakening response, Psychosom. Med. 66 (2) (2004) 207–214.
[40] A.C. Kramer, A.B. Neubauer, M. Stoffel, A. Voss, B. Ditzen, Tomorrow's gonna suck: Today's stress anticipation predicts tomorrow's post-awakening cortisol increase, Psychoneuroendocrinology 106 (2019) 38–46.
[41] R.N. Butler, The life Review: an interpretation of reminiscence in the aged, Psychiatry 26 (1) (1963) 65–76, https://doi.org/10.1080/00332747.1963.11023339.
[42] G.M. Kenyon, W.L. Randall, Restorying Our lives: Personal growth Through Autobiographical Reflection, Greenwood Publishing Group, 1997. ISBN: 0275956636.
[43] J.D. Webster, The reminiscence circumplex and autobiographical memory functions, In Memory 11 (2) (2003) 203–215, https://doi.org/10.1080/741938202.
[44] F. Raes, D. Hermans, J.M.G. Williams, P. Eelen, Reduced autobiographical memory specificity and affect regulation, Cognition and Emotion 20 (3-4) (2006) 402–429.
[45] P. Cappeliez, N. O'Rourke, Empirical validation of a model of reminiscence and health in later life, J. Gerontol. B: Psychol. Sci. Soc. Sci. 61 (4) (2006) P237–P244, https://doi.org/10.1093/geronb/61.4.P237.
[46] Lobo, A., Saz, P., & Marcos, G. (2002). MMSE: mini-mental State Exam. TEA Ediciones.
[47] N. Adler. The MacArthur Scale of Subjective Social Status, MacArthur Research Network on SES & Health, 2007.
[48] A.T. Beck, R.A. Steer, G. Brown, Beck depression inventory–II, Psychol. Assess. (1996).
[49] C.D. Spielberger, R.L. Gorsuch, R. Lushene, P. Vagg, G.J.P.A. Jacobs. Consulting Psychologists Press, Palo Alto, CA, 1983, p. 19831983.
[50] T. Montoliu, V. Hidalgo, A. Salvador, The relationship between loneliness and cognition in healthy older men and women: the role of cortisol, Psychoneuroendocrinology 107 (2019) 270–279, https://doi.org/10.1016/j.psyneuen.2019.05.024.
[51] J.P. Serrano, J.M. Latorre, J. Montañés, Life review therapy based on retrieval of specific autobiographical memories in elderly individuals with depression, in: Revista Espanola de Geriatria y Gerontologia, 40, Ediciones Doyma, S.L, 2005, pp. 220–227, https://doi.org/10.1016/s0211-139x(05)74858-7.
[52] J.M. Williams, K. Broadbent, Autobiographical memory in suicide attempters, J. Abnorm. Psychol. 95 (2) (1986) 144–149, https://doi.org/10.1037/0021-843X.95.2.144.
[53] L. Ros, J.C. Meléndez, J.D. Webster, T. Mayordomo, A. Sales, J.M. Latorre, J. P. Serrano, Reminiscence functions scale: factorial structure and its relation with mental health in a sample of Spanish older adults, Int. Psychogeriatr. 28 (9) (2016) 1521–1532, https://doi.org/10.1017/S1041610216000326.
[54] J.D. Webster, Construction and validation of the Reminiscence Functions scale, J. Gerontol. 48 (5) (1993) P256–P262, https://doi.org/10.1093/geronj/48.5.P256.
[55] J.C. Pruessner, C. Kirschbaum, G. Meinlschmid, D.H. Hellhammer, Two formulas for computation of the area under the curve represent measures of total hormone concentration versus time-dependent change, Psychoneuroendocrinology 28 (7) (2003) 916–931, https://doi.org/10.1016/S0306-4530(02)00108-7.
[56] J. Hellhammer, E. Fries, O.W. Schweisthal, W. Schlotz, A.A. Stone, D. Hagemann, Several daily measurements are necessary to reliably assess the cortisol rise after awakening: state-and trait components, Psychoneuroendocrinology 32 (1) (2007) 80–86.
[57] T. Stalder, C. Kirschbaum, B.M. Kudielka, E.K. Adam, J.C. Pruessner, S. Wüst, A. Clow, Assessment of the cortisol awakening response: expert consensus guidelines, Psychoneuroendocrinology 63 (2016) 414–432.
[58] T. Stalder, S.J. Lupien, B.M. Kudielka, E.K. Adam, J.C. Pruessner, S. Wüst, A. Clow, Evaluation and update of the expert consensus guidelines for the assessment of the cortisol awakening response (CAR), Psychoneuroendocrinology (2022) 105946, https://doi.org/10.1016/j.psyneuen.2022.105946.
[59] M. Perugini, M. Gallucci, G. Costantini, A practical primer to power analysis for simple experimental designs, Rev. Int. Psychol. Soc. 31 (1) (2018) 1–23, https://doi.org/10.5334/IRSP.181.
[60] G. Cohen, S. Taylor, Reminiscence and ageing, Ageing Soc. 18 (5) (1998) 601–610, https://doi.org/10.1017/S0144686X98007053.
[61] T.J. Barry, A.R. Sewart, E.K. Adam, R.E. Zinbarg, S. Mineka, M.G. Craske, The longitudinal association between individual differences in recall of positive specific autobiographical memories and daily cortisol, Biol. Psychol. (2021) 162, https://doi.org/10.1016/j.biopsycho.2021.108086.
[62] T.J. Barry, C.P.Y. Chiu, F. Raes, J. Ricarte, H. Lau, The neurobiology of reduced autobiographical memory specificity, in: Trends in Cognitive Sciences, 22, Elsevier Ltd, 2018, pp. 1038–1049, https://doi.org/10.1016/j.tics.2018.09.001.
[63] A.D. Askelund, S. Schweizer, I.M. Goodyer, A.-L. van Harmelen, Positive memory specificity is associated with reduced vulnerability to depression, Nat. Hum. Behav. 3 (3) (2019) 265–273, https://doi.org/10.1038/s41562-018-0504-3.
[64] W.B. Scoville, B. Milner, Loss of recent memory after bilateral hippocampal lesions, J. Neurol. Neurosurg. Psychiatr 20 (1) (1957) 11, 10.1136/jnnp.20.1.11.
[65] Clow, A., Hucklebridge, F., & Thorn, L. (2010). The cortisol awakening response in context. International review of neurobiology, 93, 153–175. https://doi.org/10.1016/S0074-7742(10)93007-9.
[66] N. Mbiydzenyuy, L. Qulu, Stress, hypothalamic-pituitary-adrenal axis, hypothalamic-pituitary-gonadal axis, and aggression, Metab. Brain Dis. 39 (2024) 1613–1636.

[67] N.K. Moog, S. Entringer, C. Heim, P.D. Wadhwa, N. Kathmann, C. Buss, Influence of maternal thyroid hormones during gestation on fetal brain development, Neuroscience 342 (2017) 68–100, https://doi.org/10.1007/s11011-024-01393-w.
[68] F. Anifantaki, P. Pervanidou, I. Lambrinoudaki, K. Panoulis, N. Vlahos, M. Eleftheriades, Maternal prenatal stress, thyroid function and neurodevelopment of the offspring: a mini review of the literature, Front. Neurosci. 15 (2021), https://doi.org/10.3389/fnins.2021.692446.
[69] G.P. Chrousos, Stress and disorders of the stress system, Nat. Rev.Endocrinol 5 (2009) 374–381, https://doi.org/10.1038/nrendo.2009.106.
[70] N. Warne, F. Rice, Links between depressive symptoms and the observer perspective for autobiographical memories and imagined events: a high familial risk study, J. Cogn. Psychol. 34 (1) (2022) 82–97, https://doi.org/10.1080/20445911.2021.1922418.