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Allostatic load, adverse childhood experiences, executive functions, and BMI status in adolescents and young adults

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Abstract

Objectives: Chronic stress induces preclinical changes in the metabolic, cardiovascular, and immune systems. This phenomenon, known as allostatic load (AL), can impair executive functions (EF), which may be even more affected in individuals with excess weight due to their characteristic inflammatory state and cardiometabolic changes. Adverse childhood experiences (ACEs) contribute to AL and may influence executive functioning presumably via alterations within the hypothalamic–pituitary axis, including epigenetic modifications. We assess the relationship between AL and EF in youth with and without excess weight, and the effect ACEs on executive functioning.

Methods: One hundred eighty-two adolescents and young adults (85 with normal weight and 97 with overweight/obesity; 10–21 years) were recruited. The estimated AL index included the following: systolic and diastolic blood pressure, glycated hemoglobin, high- and low-density lipoprotein cholesterol, triglycerides, high-sensitivity C-reactive protein, fibrinogen, and cortisol. ACEs were measured using the Juvenile Victimization Questionnaire. The neuropsychological evaluation included the assessment of inhibition, working memory, and cognitive flexibility processes.

Results: AL was not significantly associated with executive functioning, and this relationship did not depend on body-weight status. ACEs, available for 57 of 182 participants, were significantly associated with poorer executive functioning.

Conclusions: Our study shows that AL is not associated with executive functioning in adolescents and young adults. Since the current sample was young, we hypothesize that a longer exposure to AL might be required for its negative effects to surface. Nevertheless, exposure to early adversity seems to be associated with poorer executive functioning in youth.

1 | INTRODUCTION

Stress involves allostasis, a complex process where the organism initiates physiological multisystemic adaptations to overcome a challenging scenario and return to a new stable state. When the brain interprets a situation as a threat, primary mediators in the form of neuroendocrine responses prepare the organism for a fight-or-flight response. Such adaptations are necessary to maintain stability through adversity but, when facing long-term stress, secondary outcomes take place as preclinical variations in metabolic, cardiovascular, and immune systems. This preclinical state is known as allostatic load (AL) and, if sustained over time, tertiary outcomes—clinical disorders—can arise (Juster et al., 2010).

Throughout adolescence, there is an increased sensitivity to stress and a change in the biological responses to stress, making this period particularly vulnerable to its effects (Whelan et al., 2021). For example, the prefrontal cortex (PFC) is richer in cortisol receptors during this time of development, making it more susceptible to the neurocognitive consequences of stress (Tottenham & Galván, 2016). The PFC includes brain regions that support executive functions (EF), namely inhibition, cognitive flexibility, and working memory, key functions that collectively facilitate the achievement of goals (Diamond, 2013). Cognitive dysfunction is known to be one of the tertiary outcomes of AL (Juster et al., 2010), and a recent meta-analysis in adults suggested that higher AL values were associated with poorer EF (D'Amico et al., 2020).

Chronic stress can be triggered by multiple reasons but here we focus on excess weight and early life adversity. Excess weight has been broadly related to states of low-grade chronic inflammation and cardiometabolic alterations that can not only initiate or add up to the effects of AL (Suvarna et al., 2020) but also hinder executive functioning (Farruggia & Small, 2019). Similarly, the accumulation of adverse childhood experiences (ACEs) across childhood can trigger adaptative multisystemic responses that may in turn have long-lasting effects on cognition among children (Guinosso et al., 2016) and adults (Hawkins et al., 2021). Moreover, the nature of the ACEs has also been described as a possible contributor to cognitive dysfunction (McLaughlin et al., 2014).

To the best of our knowledge, although previous works have explored the association between AL and EF in adult populations (D'Amico et al., 2020), none have focused on adolescents and young adults. Moreover, given that the literature suggests a relationship between body mass index (BMI) and AL in pediatric and adult samples (Cedillo et al., 2019; Suvarna et al., 2020), we explore whether the association between AL and EF might be different according to the BMI group. This has already been done in adult samples (Ottino-González et al., 2019), but not in adolescents. On the other hand, ACEs are strongly associated with psychopathology, and psychopathology affects cognitive functioning. Therefore, studying the extent to which ACEs affect EF in a sample without mental health diagnoses may help to disentangle this relationship without the influence of such an important confounder.

Thus, the present study fills a gap in the literature by evaluating, in adolescents and young adults, the relationship between (i) AL and EF, and (ii) AL and EF according to BMI. Additionally, we assessed how (iii) ACEs—from infancy to adolescence—as a form of chronic stress may affect EF. We hypothesized that (i) a higher AL index will be related to lower EF, (ii) and that this relationship will be stronger in participants with overweight/obesity. Also, we hypothesize that (iii) higher ACEs will be associated with poorer EF.

2 | MATERIALS AND METHODS

Recruitment and data collection took place between 2010 and 2022 and included three different protocols. Potential candidates ($n = 205$) underwent a medical evaluation and a blood draw either in person at the Hospital de Terrassa-Consorci Sanitari de Terrassa or at home due to the SARS-CoV-2 outbreak. The pubertal stage was determined in this visit according to the Tanner scale of sexual maturity. A neuropsychological evaluation, either in-person or online, was completed in a second visit. The inclusion criterion was being aged between 10 and 21 years old. Exclusion criteria were having (i) underweight, (ii) high sensitivity C-reactive protein (hs-CRP) >10 mg/L as a likely indicator of acute infection (Pearson et al., 2003), (iii) psychiatric, neurological, developmental, cardiometabolic, or systemic diagnosis, (iv) global cognitive impairment, or (v) bulimia-like behaviors. Exclusion criteria application led to a final sample size of 182. Most participants self-identified as White and Spaniard ($n = 170$). Ten participants self-identified as Latino, and two participants did not report their race or ethnicity. The socioeconomic status, assessed by monthly family income, was only available for 96 participants. From the sample used in this study, some participants were already included in previous works (Prunell-Castañé, Beyer, et al., 2023; Prunell-Castañé, Jurado, et al., 2023).

This study was approved by the Institutional Ethics Committee of the University of Barcelona (Institutional Review Board IRB00003099, assurance number FWA00004225). The research was conducted by the

Helsinki Declaration. Written informed consent was obtained from all participants, or their legal guardians in underage participants before they entered into the study.

2.1 | Anthropometric measurement

Participants wore light clothing and no shoes for height and weight measurments. BMI was calculated as kilogram per square meter and transformed into BMI *z*-scores (BMIz) after CDC growth charts with the R package *cdcanthro*. Since BMIz can be calculated for participants up to 20 years, the BMIz for participants aged 20 and 21 years was calculated as if they were 19 years and 11 months (Must & Anderson, 2006). We classified participants as normal weight or overweight/obesity using the BMI cutoffs from Cole and Lobstein (2012) for underage participants, and the 25 kg/m^2 BMI cutoff from the World Health Organization (2021) for participants aged 18–21 years.

2.2 | AL index

The AL index included nine biomarkers representing cardiovascular (systolic blood pressure and diastolic blood pressure), metabolic (glycated hemoglobin, high-density lipoprotein cholesterol (HDL), low-density lipoprotein cholesterol (LDL), and triglycerides), immune (hs-CRP and fibrinogen), and neuroendocrine (cortisol) systems. Supplementary material S1 provides information on how the concentrations of hs-CRP, fibrinogen, and cortisol were determined. Anthropometric measures are usually included in the calculation of AL (Whelan et al., 2021). However, we aimed to assess differences in AL between BMI groups. Therefore, including anthropometric measurements in the AL index would be a circular analysis, since they strongly correlate with BMI. Given this, we did not consider anthropometric measurements in the AL calculation but rather included other biomarkers that broadly represent the metabolic system.

We used two different methods to calculate the AL index. Although the high-risk percentile is the most used in the literature, we additionally calculated the AL as a composite *z*-score, as it uses the full continuum of data (Carbone et al., 2022). For both methods, a prorated AL index was computed in participants with missing values. Supplementary material provides a more thorough explanation of both methods.

- In the first method, the AL index was the sum of all nine biomarkers' dichotomous scores, that is, each participant surpassing the biomarker's high-risk percentile scored 1 on that biomarker (i.e., ≥75th or ≤25th in the case of HDL cholesterol). The sum of all biomarkers constituted the AL index (range 0–9), with higher scores meaning higher AL. Cutoff scores were based on the normal weight group ($n = 85$) to prevent setting the thresholds too high by including participants with overweight/obesity, as these are more likely to have higher values in all biomarkers (Ottino-González et al., 2017). Additionally, we set different cutoffs for males and females (Kerr et al., 2020), and for the time of blood draw (morning or afternoon) in biomarkers that presented statistical differences ($p < .05$). Table 1 shows the cutoff points for all biomarkers.
- In the second method, all biomarkers were *z*-scaled and added into a composite with greater scores meaning higher AL. The HDL *z*-score was reverse-scored so that higher values reflected greater alteration. Additionally, we adjusted the AL composite score to sex and blood draw daytime. To do so, we used the standardized residuals of the linear regression: AL composite score ~ sex + blood draw daytime.

2.3 | Neuropsychological assessment

The neuropsychological assessment included in-person and online evaluation of EF and ACEs. A more detailed description of these assessments can be found in Supplementary Material. Working memory was assessed using the Letter–Number Sequencing scalar score of the WAIS-III/WISC-IV (Wechsler, 2002, 2007). Inhibition was evaluated using the Stroop color and word test interference score (Golden, 1995). Cognitive flexibility was assessed using the perseverative raw errors from the computerized version of the Wisconsin Card Sorting Test (Heaton, 1999). We additionally calculated a composite to assess EF globally. Higher scores in working memory, inhibition, and EF composite, and lower scores in cognitive flexibility indicated better performance.

Furthermore, the Juvenile Victimization Questionnaire (Pereda et al., 2014) was used to assess ACEs exposure among participants. It is a self-reported questionnaire translated into Spanish and validated in the Spanish population that focuses on six types of victimization from infancy to adolescence: conventional crimes, caregiver victimization, peer and sibling victimization, sexual victimization, witnessing and indirect victimization, and electronic victimization. Higher scores were indicative of higher victimization. Only participants of the third protocol ($n = 57$) received this questionnaire.

TABLE 1 Allostatic load cutoff points for the high-risk percentile calculation method.

	Females			Males		
	Both	**Morning**	**Afternoon**	**Both**	**Morning**	**Afternoon**
Diastolic blood pressure (mmHg)	-	65.75	75.5	72.75	-	-
Systolic blood pressure (mmHg)	112.5	-	-	124.5	-	-
Glycated hemoglobin (%)	-	5.17	5.4	-	5.3	5.37
HDL (mmol/L)	1.42	-	-	1.3	-	-
LDL (mmol/L)	2.6	-	-	-	2.5	2.05
Triglycerides (mmol/L)	0.865	-	-	0.95	-	-
hs-CRP (mg/L)	0.775	-	-	0.9	-	-
Cortisol (nmol/L)	-	642.82	213.5	-	470.7	250
Fibrinogen (g/L)	3.72	-	-	-	3.25	3.83

Abbreviations: HDL: high-density lipoprotein cholesterol; hs-CRP: high-sensitivity C-reactive protein; LDL: low-density lipoprotein cholesterol.

2.4 | Statistical analysis

The analytical plan of this paper was preregistered in Open Science Framework (osf.io/37t2e). Data manipulation and statistical procedures were performed in R (v.4.0.5) and RStudio (v.2022.02.3). Independent sample *T*-tests, Mann–Whitney *U* tests, and Chi-squared tests were used to analyze between-group differences in sample characteristics. We assessed potential differences in cognitive variables in participants who underwent the neuropsychological assessment in-person versus online, as well as the interaction of confounding variables such as age, sex, and BMI group with the modality of evaluation (see Table S1). Regarding ACEs, we compared the estimated prevalence of juvenile victimization in Spain with our data. The following methods were used for both AL index calculations (sum of the high-risk percentile of the sample distribution and composite mean z-score):

- Semi-partial correlations in the entire sample ($n = 182$) were conducted between AL and EF (*ppcor* package, v.1.1). We controlled EF for age, sex, BMIz, and estimated intelligence (WAIS-III/WISC-IV Vocabulary subtest scalar score). Then, to further assess the effect of BMI on the relationship among AL and EF, we repeated the analysis stratifying our data into two BMI groups (normal weight and overweight/obesity) while still adjusting EF for age, sex and estimated intelligence. The resulting *p*-values from multiple tests were adjusted with a false discovery rate (FDR). FDR-corrected *p*-values <0.05 were considered significant. For the group-specific correlations, we assessed whether the correlation coefficients were different between BMI groups (*cocor* package, v.1.1.4).
- Using a subsample of $n = 57$, multiple regression determined how ACEs predicted EF. Age, sex, BMIz, and estimated intelligence were included as nuisance covariates. Multiple testing was controlled by FDR correction. Mediation analysis, as specified in the preregistered analytical plan, could not be performed due to the lack of association between ACEs (X) and AL (mediator).

We examined descriptive characteristic differences between the whole sample and the subsample. Additionally, we performed a sensitivity analysis excluding prepubescent participants.

3 | RESULTS

3.1 | AL index, EF, and BMI

Groups did not differ for sex, age, anxiety/depression symptoms, or monthly family income ($p > .05$). As expected, the overweight/obesity group had higher AL index (Figure 1). Also, the overweight/obesity group performed worse in the overall assessment of EF. Table 2 provides descriptive characteristics for BMI groups.

Using both AL indexes and after FDR correction, semi-partial correlations did not reveal a significant association between AL and any EF, including its composite, either for the whole sample or at the BMI group-specific level. At an uncorrected level, the semi-partial correlation between cognitive flexibility and the AL composite score was significant for the overweight/obesity group ($sr = 0.21$, $p = .04$). Semi-partial correlation coefficients were also not different between groups (Table 3).

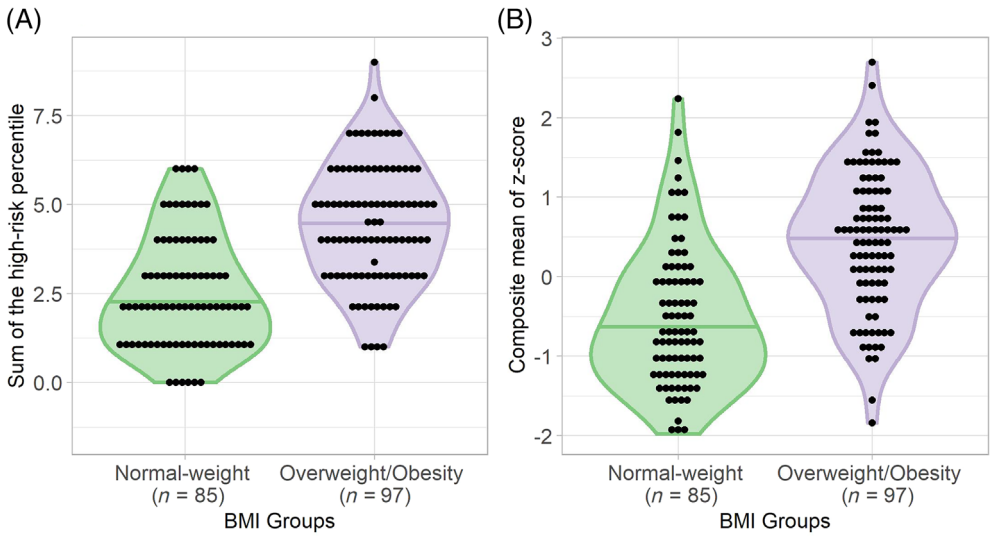

FIGURE 1 Allostatic load (AL) indexes (A: AL composite mean of *z*-score, B: AL high-risk percentile sum) comparison between body mass index (BMI) groups.

TABLE 2 Sample descriptive characteristics.

	NW ($n = 85$)		OW/OB ($n = 97$)			
	Mean (SD)	**Range**	**Mean (SD)**	**Range**	**Test statistic**	***p* value**
Age (years)	15.8 (2.92)	10, 21	15.06 (2.43)	10, 21	$W = 4674$	0.12
Sex (*n* females, %)	43 (50.6%)	-	46 (47.42%)	-	$\chi^2 = 0.07$	0.78
Prepubescents (*n*, %)	6 (7%)	-	4 (4.12%)	-	$\chi^2 = 0.29$	0.59
Monthly family income (€)						
300–899 (*n*, %)	4 (4.7%)	-	3 (3.1%)	-	$\chi^2 = 1.79$	0.77
900–1499 (*n*, %)	9 (10.59%)	-	9 (9.28%)	-		
1500–2099 (*n*, %)	16 (18.82%)	-	10 (10.31%)	-		
2100–2699 (*n*, %)	8 (9.41%)	-	11 (11.34%)	-		
≥2700 (*n*, %)	14 (16.48%)	-	12 (12.36%)	-		
N.A. (*n*, %)	34 (40%)	-	52 (53.61%)	-		
BMI *z*-score	−0.07 (0.62)	−1.76, 0.82	1.81 (0.42)	0.95, 3.02	$W = 0$	<0.001
AL index high-risk percentile	2.47 (1.6)	0, 6	4.43 (1.67)	1, 9	$W = 1690$	<0.001
AL index composite score	−0.53 (0.88)	−1.97, 2.24	0.46 (0.87)	−1.84, 2.7	$W = 1704$	<0.001
HADS anxiety	4.83 (2.55)	0, 10	4.54 (2.72)	0, 10	$W = 4390$	0.45
HADS depression	1.98 (1.75)	0, 6	2.49 (2.27)	0, 9	$W = 3688$	0.21
Estimated intelligence	11.26 (2.32)	7, 19	10.82 (2.37)	7, 19	$W = 4546$	0.23
Working memory	11.63 (2.42)	5, 17	10.94 (2.7)	5, 18	$T = 1.83$	0.07
Cognitive Flexibility	14.87 (10.91)	4, 51	16.05 (12.01)	4, 65	$W = 3797$	0.43
Inhibition	4.75 (6.54)	−9.7, 23.5	3.77 (7.06)	−16.9, 22.75	$W = 4340$	0.54
EF composite	0.09 (0.66)	−2.02, 1.88	−0.08 (0.66)	−1.87, 1.43	$W = 4939$	0.02

Note: We provide mean (SD) and range for numerical variables, and n counts (%) for categorical variables (sex, prepubescents, monthly family income). Estimated intelligence was assessed by the Weschler Adults Intelligence Scale-III/Weschler Intelligence Scale for Children-IV (WAIS-III/WISC-IV) vocabulary subtest scalar score. Working memory was assessed using the Letter-Number Sequencing scalar score of the WAIS-III/WISC-IV. Cognitive flexibility was assessed by the Wisconsin Card Sorting Test perseverative raw errors. Inhibition was assessed by the Stroop Test Interference score.
Abbreviations: AL, allostatic load; BMI, body mass index; EF, executive functions; HADS, hospital anxiety and depression scale; NA, not available; NW, normal weight; OW/OB, overweight/obesity.

TABLE 3 Spearman's semi-partial correlation estimates between executive functions and allostatic load (AL) index using two AL index calculations.

		AL high-risk percentile		AL composite mean of z-score	
		Spearman semi-partial correlation estimate (sr)	sr comparison between BMI groups	Spearman semi-partial correlation estimate (sr)	sr comparison between BMI groups
Working memory	Whole sample	−0.03	-	0.001	-
	NW group	0.03	$Z = 0.49$ $p = 0.62$	−0.005	$Z = -0.16$ $p = 0.87$
	OW/OB group	−0.04		0.02	
Cognitive Flexibility	Whole sample	0.07	-	0.1	-
	NW group	0.04	$Z = -0.71$ $p = 0.47$	0.08	$Z = -0.86$ $p = 0.39$
	OW/OB group	0.14		0.21*	
Inhibition	Whole sample	−0.004	-	0.01	-
	NW group	−0.02	$Z = -0.45$ $p = 0.65$	−0.004	$Z = -0.34$ $p = 0.74$
	OW/OB group	0.05		0.05	
EF Composite	Whole sample	−0.07	-	−0.08	-
	NW group	−0.007	$Z = 0.88$ $p = 0.38$	−0.04	$Z = 0.69$ $p = 0.48$
	OW/OB group	−0.14		−0.15	

Note: All FDR-corrected p-values of the *sr* estimates were >0.05.

Abbreviations: AL, allostatic load; BMI, body mass index; EF, executive functions; NW, normal weight; OW/OB, overweight/obesity.

*Significant at an uncorrected level ($p = 0.04$).

Sensitivity analyses without prepubescent participants provided similar results (Table S2).

3.2 | ACEs and EF

The descriptive characteristics of the subsample ($n = 57$, Table S3) were not statistically different from the whole sample ($n = 182$). There were no differences in the prevalence of ACEs between the study by Pereda et al. (2014) and our study (Table S4).

Multiple regression analyses (Table 4) indicated that higher ACEs were associated with worse performance in cognitive flexibility ($b = 0.07$, $p_{\text{b-value}} = 0.0009$, Adj $R^2 = 0.26$, $\text{FDR}_{\text{model}} = 0.003$) and the overall EF ($b = -0.09$, $\text{P}_{\text{b-value}} = 0.0005$, Adj $R^2 = 0.2$, $\text{FDR}_{\text{model}} = 0.01$). Although higher ACEs were associated with poorer inhibitory control ($b = -0.66$, $p_{\text{b-value}} = 0.02$), the model only reached significance at a trend level (Adj $\text{R}^2 = 0.1$, $\text{FDR}_{\text{model}} = 0.09$). Working memory was not associated with ACEs. Moreover, age was significantly associated with cognitive flexibility, inhibitory control, and overall EF ($p_{\text{b-values}} < 0.05$). Sensitivity analyses without prepubescent participants ($n = 50$) provided similar results (Table S5).

4 | DISCUSSION

In this preregistered study, we evaluated the relationship between EF and AL in adolescents and young adults, and how this relationship might differ according to BMI status. Furthermore, we studied the effect of ACEs on EF. Importantly, our approach included two different calculations of the AL index. As highlighted in a recent review (Carbone et al., 2022), the sum of the high-risk percentiles of the sample distribution is the most commonly used method in the literature, whereas composite mean z-scores permits using the full continuum of data. Here, regardless of the method chosen, adolescents and young adults with overweight/obesity exhibited greater levels of AL. This is not an unexpected result, as BMI or

TABLE 4 Multiple regression coefficients for the working memory, cognitive flexibility, inhibition, and executive functions composite models.

	Predictors							
Variable of interest		**ACEs**	**Sex**	**BMIz**	**Age**	**Intelligence**	**Adj R^2**	**FDR**
Working memory	*b*	−0.22	−0.72	−0.34	0.19	0.05	0.002	0.41
	95% CI	−0.44, 0.006	−2.32, 0.92	−1.11, 0.43	−0.12, 0.5	−0.27, 0.38		
	p	0.06	0.38	0.38	0.22	0.75		
Cognitive flexibility	*b*	0.07	−0.05	−0.11	−0.12	0.01	0.26	0.003
	95% CI	0.03, 0.11	−0.35, 0.24	−0.25, 0.03	−0.17, −0.06	−0.05, 0.07		
	p	0.0009	0.72	0.11	0.00008	0.72		
Inhibition	*b*	−0.66	1.53	−0.23	0.86	0.12	0.1	0.09
	95% CI	−1.18, −0.13	−2.34, 5.4	−2.05, 1.58	0.12, 1.59	−0.64, 0.88		
	p	0.02	0.43	0.8	0.02	0.75		
EF composite	*b*	−0.09	−0.02	−0.01	0.11	0.01	0.2	0.01
	95% CI	−0.14, −0.04	−0.37, 0.34	−0.18, 0.15	0.04, 0.18	−0.06, 0.08		
	p	0.0005	0.92	0.85	0.002	0.76		

Note: Working memory was assessed using the Letter-Number Sequencing scalar score of the Weschler Adults Intelligence Scale-III/Weschler Intelligence Scale for Children-IV (WAIS-III/WISC-IV). Inhibition was assessed with the Stroop Test Interference score. Cognitive flexibility was assessed using the Wisconsin Card Sorting Test perseverative raw errors, which was transformed into its logarithmic form. Adverse childhood experiences were assessed with the Juvenile Victimization Questionnaire. Estimated intelligence was assessed with the Vocabulary scalar score of the WAIS-III/WISC-IV. Unstandardized betas were reported.

Abbreviations: ACEs: adverse childhood experiences; AL: allostatic load; BMIz: body mass index *z*-score; EF: executive functions; FDR: false discovery rate; Intelligence: estimated intelligence.

other measures of adiposity are almost universally included in estimated AL indices. Also, adolescents and young adults with overweight/obesity performed worse in EF. However, the relationship between AL and EF was not significant either for the whole sample (irrespective of BMI) or when assessing BMI groups separately. Interestingly, we found that higher exposure to ACEs was associated with poorer EF.

4.1 | Executive functioning, AL, and BMI

Cognition is known to be sensitive to physiological dysregulations (Juster et al., 2010), such as AL or obesity. Concerning AL, a meta-analysis—with samples formed mostly by senior participants—reported that poorer EF were related to a higher AL (D'Amico et al., 2020). Consistently, a recent study with adults (Beydoun et al., 2023) described an association between worse EF and higher AL. Interestingly, and despite all the evidence for the existing relationship between EF and AL in adults, we did not find significant results in adolescents and young adults. Given that the AL model suggests that the physiological burden and disease states of chronic stress exposure accumulate over time, we speculate that adolescents and young adults may not have had sufficient exposure to the effects of AL. Notably, we found an association at the trend level between poorer cognitive flexibility and higher AL composite scores, but only in participants with overweight/obesity. Previous research has reported a relationship between AL and BMI in children and adolescents (Calcaterra et al., 2019), and concluded that there is a cumulative physiological dysregulation in higher BMI categories. Furthermore, a recent study suggested that BMI might be one of the earliest signs of increased AL in adolescents (King et al., 2019). Thus, it is conceivable that excess weight, which has also been consistently associated with poorer EF regardless of age (Yang et al., 2018), could potentiate physiological stress status (i.e., low-grade inflammation and cardiometabolic changes) and favor its consequences.

4.2 | ACEs and executive functioning

Exposure to ACEs can cause health consequences not only within the vulnerable developmental window they occur but also into adulthood (Finlay et al., 2022). Here, we found that ACEs were associated with worse EF in adolescents and young adults, as reported elsewhere (Johnson et al., 2021; Li et al., 2013; Lund et al., 2020).

Theoretically, exposure to ACEs could generate epigenetic modifications (Juster et al., 2016) and alterations in the activity of the hypothalamic–pituitary–adrenal axis (responsible for mobilizing the primary mediators of AL), subsequently inducing changes in the PFC and in the development of EF (Lund et al., 2020). Additionally, the timing, duration, type, and severity of the ACEs might influence the emergence of cognitive dysregulations (De Bellis & Zisk, 2014). In our study, the results of the multiple regression analysis showed that age was positively associated with EF, which is consistent with the ongoing maturation of the PFC observed during adolescence (Tervo-Clemmens et al., 2023). However, these age-related increases in cognitive performance may not be sufficient to compensate for the detrimental effects of ACEs, whose exposure also increases with age (see Figure S1). Moreover, individuals who have survived more severe forms of ACEs might display greater cognitive changes. Individual characteristics, such as resilience and vulnerability, might also shape psychological responses to ACEs. A recent study with adults (D'Amico et al., 2022) reported that AL mediated the relationship between ACEs and cognitive function. Given that we could not perform mediation analysis, future studies should replicate these results in adolescent and young adult samples.

4.3 | Strengths and limitations

Strengths of our study include its preregistration, using two methods to calculate the AL index to ensure that the results were not driven by a specific calculation method, and controlling for sex differences in the AL index calculation. Moreover, other than overweight/obesity, our sample did not have any medical condition (tertiary outcome) that could increase the AL index, or blur whether such condition predated or emerged from allostatic overload. The present study also has limitations. The retrospective and self-report recall of ACEs might diminish their accuracy. The tests chosen for neuropsychological assessment may not be sensitive enough to detect differences in young and predominantly healthy samples. Socioeconomic status, which is associated with EF (Lawson et al., 2018), was not included as a confounding variable due to a large proportion of missing values. Also, 95% of the sample identified themselves as White, a race that does not experience certain adverse events such as racism and is less likely to suffer from poverty. These two dimensions—poverty and racism—are known to be related to higher AL (Miller et al., 2021; Thomas Tobin & Hargrove, 2022). Given this, future studies with a more diverse sample size are needed to confirm our results and to evaluate potential differences in the relationship between AL and EF in adolescents and young adults according to weight status and psychosocial risk exposure.

5 | CONCLUSIONS

We provide evidence that, in adolescents and young adults, overweight/obesity is associated with higher levels of AL and worse executive functioning. However, we did not find AL to be related to EF either for the whole sample or when assessing BMI groups separately. We hypothesize that the AL burden might affect cognition only if sustained over time. Still, we found that exposure to ACEs was associated with poorer executive functioning. This could be taken to suggest that exposure to early chronic psychological stress is related to dysregulations that might detriment cognitive functions.

AUTHOR CONTRIBUTIONS

Anna Prunell-Castañé: Investigation, Conceptualization, Formal analysis, Writing—Original Draft; **Maite Garolera**: Conceptualization, Writing—review & editing, Funding acquisition; **Jonatan Ottino-González**: Investigation, Writing—review & editing; **María Ángeles Jurado**: Conceptualization, Writing—review & editing, Funding acquisition.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

Beydoun, H. A., Beydoun, M. A., Maldonado, A. I., Fanelli-Kuczmarski, M. T., Weiss, J., Evans, M. K., & Zonderman, A. B. (2023). Allostatic load and cognitive function among urban adults in the healthy aging in neighborhoods of diversity across the life span study. *Journal of Alzheimer's Disease*, *92*(2), 425–443. https://doi.org/10.3233/JAD-220888

Calcaterra, V., Vinci, F., Casari, G., Pelizzo, G., de Silvestri, A., De Amici, M., Albertini, R., Regalbuto, C., Montalbano, C., Larizza, D., & Cena, H. (2019). Evaluation of allostatic load as a marker of chronic stress in children and the importance of excess weight. *Frontiers in Pediatrics*, *7*, 1–5. https://doi.org/10.3389/fped.2019.00335

Carbone, J. T., Clift, J., & Alexander, N. (2022). Measuring allostatic load: Approaches and limitations to algorithm creation. *Journal of Psychosomatic Research*, *163*, 111050. https://doi.org/10.1016/j.jpsychores.2022.111050

Cedillo, Y. E., Murillo, A. L., & Fernández, J. R. (2019). The association between allostatic load and anthropometric measurements among a multiethnic cohort of children. *Pediatric Obesity*, *14*(6), 1–8. https://doi.org/10.1111/ijpo.12501

Cole, T. J., & Lobstein, T. (2012). Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. *Pediatric Obesity*, *7*, 284–294. https://doi.org/10.1111/j.2047-6310.2012.00064.x

D'Amico, D., Amestoy, M. E., & Fiocco, A. J. (2020). The association between allostatic load and cognitive function: A systematic and meta-analytic review. *Psychoneuroendocrinology*, *121*, 104849. https://doi.org/10.1016/j.psyneuen.2020.104849

D'Amico, D., Amestoy, M. E., & Fiocco, A. J. (2022). The mediating role of allostatic load in the relationship between early life adversity and cognitive function across the adult lifespan. *Psychoneuroendocrinology*, *141*, 105761.

De Bellis, M. D., & Zisk, A. (2014). The biological effects of childhood trauma. *Child and Adolescent Psychiatric Clinics of North America*, *23*(2), 185–222. https://doi.org/10.1016/j.chc.2014.01.002

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Farruggia, M. C., & Small, D. M. (2019). Effects of adiposity and metabolic dysfunction on cognition: A review. *Physiology and Behavior*, *208*, 112578.

Finlay, S., Roth, C., Zimsen, T., Bridson, T. L., Sarnyai, Z., & McDermott, B. (2022). Adverse childhood experiences and allostatic load: A systematic review. *Neuroscience and Biobehavioral Reviews*, *136*, 104605. https://doi.org/10.1016/j.neubiorev.2022.104605

Golden, C. J. (1995). *STROOP, test de colores y palabras*. TEA Ediciones.

Guinosso, S. A., Johnson, S. B., & Riley, A. W. (2016). Multiple adverse experiences and child cognitive development. *Pediatric Research*, *79*(1–2), 220–226. https://doi.org/10.1038/pr.2015.195

Hawkins, M. A. W., Layman, H. M., Ganson, K. T., Tabler, J., Ciciolla, L., Tsotsoros, C. E., & Nagata, J. M. (2021). Adverse childhood events and cognitive function among young adults: Prospective results from the national longitudinal study of adolescent to adult health. *Child Abuse and Neglect*, *115*, 105008. https://doi.org/10.1016/j.chiabu.2021.105008

Heaton, R. K. (1999). *Wisconsin card sorting test: Computer version 4* (Research ed.). Psychological Assessment Resources.

Johnson, D., Policelli, J., Li, M., Dharamsi, A., Hu, Q., Sheridan, M. A., McLaughlin, K. A., & Wade, M. (2021). Associations of early-life threat and deprivation with executive functioning in childhood and adolescence: A systematic review and meta-analysis. *JAMA Pediatrics*, *175*(11), 1–10. https://doi.org/10.1001/jamapediatrics.2021.2511

Juster, R. P., McEwen, B. S., & Lupien, S. J. (2010). Allostatic load biomarkers of chronic stress and impact on health and cognition. *Neuroscience and Biobehavioral Reviews*, *35*(1), 2–16. https://doi.org/10.1016/j.neubiorev.2009.10.002

Juster, R. P., Russell, J. J., Almeida, D., & Picard, M. (2016). Allostatic load and comorbidities: A mitochondrial, epigenetic, and evolutionary perspective. *Development and Psychopathology*, *28*(4), 1117–1146. https://doi.org/10.1017/S0954579416000730

Kerr, P., Kheloui, S., Rossi, M., Désilets, M., & Juster, R. P. (2020). Allostatic load and women's brain health: A systematic review. *Frontiers in Neuroendocrinology*, *59*, 100858. https://doi.org/10.1016/j.yfrne.2020.100858

King, A. L., Garnier-Villarreal, M., Simanek, A. M., & Johnson, N. L. (2019). Testing allostatic load factor structures among adolescents: A structural equation modeling approach. *American Journal of Human Biology*, *31*(4), 1–11. https://doi.org/10.1002/ajhb.23242

Lawson, G. M., Hook, C. J., & Farah, M. J. (2018). A meta-analysis of the relationship between socioeconomic status and executive function performance among children. *Developmental Science*, *21*, e12529. https://doi.org/10.1111/desc.12529

Li, Y., Dong, F., Cao, F., Cui, N., Li, J., & Long, Z. (2013). Polyvictimization and executive functions in junior college students. *Scandinavian Journal of Psychology*, *54*(6), 485–492. https://doi.org/10.1111/sjop.12083

Lund, J. I., Toombs, E., Radford, A., Boles, K., & Mushquash, C. (2020). Adverse childhood experiences and executive function difficulties in children: A systematic review. *Child Abuse and Neglect*, *106*, 104485. https://doi.org/10.1016/j.chiabu.2020.104485

McLaughlin, K. A., Sheridan, M. A., & Lambert, H. K. (2014). Childhood adversity and neural development: Deprivation and threat as distinct dimensions of early experience. *Neuroscience and Biobehavioral Reviews*, *47*, 578–591. https://doi.org/10.1016/j.neubiorev.2014.10.012

Miller, H. N., LaFave, S., Marineau, L., Stephens, J., & Thorpe, R. J. (2021). The impact of discrimination on allostatic load in adults: An integrative review of literature. *Journal of Psychosomatic Research*, *146*, 110434. https://doi.org/10.1016/j.jpsychores.2021.110434

Must, A., & Anderson, S. E. (2006). Body mass index in children and adolescents: Considerations for population-based applications. *International Journal of Obesity*, *30*(4), 590–594. https://doi.org/10.1038/sj.ijo.0803300

Ottino-González, J., Jurado, M. A., García-García, I., Caldú, X., Prats-Soteras, X., Tor, E., Sender-Palacios, M. J., & Garolera, M. (2019). Allostatic load and executive functions in overweight adults. *Psychoneuroendocrinology*, *106*, 165–170. https://doi.org/10.1016/j.psyneuen.2019.04.009

Ottino-González, J., Jurado, M. A., García-García, I., Segura, B., Marqués-Iturria, I., Sender-Palacios, M. J., Tor, E., Prats-Soteras, X., Caldú, X., Junqué, C., & Garolera, M. (2017). Allostatic load is linked to cortical thickness changes depending on body-weight status. *Frontiers in Human Neuroscience*, *11*, 1–11. https://doi.org/10.3389/fnhum.2017.00639

Pearson, T. A., Mensah, G. A., Alexander, R. W., Anderson, J. L., Cannon, R. O., Criqui, M., Fadl, Y. Y., Fortmann, S. P., Hong, Y., Myers, G. L., Rifai, N., SmithJr, S. C., Taubert, K., Tracy, R. P., & Vinicor, F. (2003). Markers of inflammation and cardiovascular disease: Application to clinical and public health practice: A statement for healthcare professionals from the centers for disease control and prevention and the American Heart Association. *Circulation*, *107*(3), 499–511. https://doi.org/10.1161/01.CIR.0000052939.59093.45

Pereda, N., Guilera, G., & Abad, J. (2014). Victimization and polyvictimization of Spanish children and youth: Results from a community sample. *Child Abuse and Neglect*, *38*(4), 640–649. https://doi.org/10.1016/j.chiabu.2014.01.019

Prunell-Castañé, A., Beyer, F., Witte, V., Sánchez Garre, C., Hernán, I., Caldú, X., Jurado, M. Á., & Garolera, M. (2023). From the reward network to whole-brain metrics: Structural connectivity in adolescents and young adults according to body mass index and genetic risk of obesity. *International Journal of Obesity*, *48*, 567–574. https://doi.org/10.1038/s41366-023-01451-w

Prunell-Castañé, A., Jurado, M. Á., Ottino-González, J., Prats-Soteras, X., Sánchez Garre, C., Cano Marco, N., Gómez-Pablos, P. S., García-García, I., & Garolera, M. (2023). Beyond BMI: Cardiometabolic measures as predictors of impulsivity and white matter changes in adolescents. *Brain Structure and Function*, *228*(3), 751–760. https://doi.org/10.1007/s00429-023-02615-0

Suvarna, B., Suvarna, A., Phillips, R., Juster, R. P., McDermott, B., & Sarnyai, Z. (2020). Health risk behaviours and allostatic load: A systematic review. *Neuroscience and Biobehavioral Reviews*, *108*, 694–711. https://doi.org/10.1016/j.neubiorev.2019.12.020

Tervo-Clemmens, B., Calabro, F. J., Parr, A. C., Fedor, J., Foran, W., & Luna, B. (2023). A canonical trajectory of executive function maturation from adolescence to adulthood. *Nature Communications*, *14*(1), 1–17. https://doi.org/10.1038/s41467-023-42540-8

Thomas Tobin, C. S., & Hargrove, T. W. (2022). Race, lifetime SES, and allostatic load among older adults. *Journals of Gerontology: Series A Biological Sciences and Medical Sciences*, *77*(2), 347–356. https://doi.org/10.1093/gerona/glab160

Tottenham, N., & Galván, A. (2016). Stress and the adolescent brain: Amygdala-prefrontal cortex circuitry and ventral striatum as developmental targets. *Neuroscience and Biobehavioral Reviews*, *70*, 217–227. https://doi.org/10.1016/j.neubiorev.2016.07.030

Wechsler, D. (2002). *WAIS III. Escala de Inteligencia de Wechsler para Adultos III*. TEA.

Wechsler, D. (2007). *WISC-IV: Escala de Inteligencia de Wechsler para Niños-IV* (2nd ed.). TEA.

Whelan, E., O'Shea, J., Hunt, E., & Dockray, S. (2021). Evaluating measures of allostatic load in adolescents: A systematic review. *Psychoneuroendocrinology*, *131*, 105324. https://doi.org/10.1016/j.psyneuen.2021.105324

World Health Organization. (2021). Obesity and overweight. Retrieved from. https://www.who.int/en/news-room/fact-sheets/detail/obesity-and-overweight

Yang, Y., Shields, G. S., Guo, C., & Liu, Y. (2018). Executive function performance in obesity and overweight individuals: A meta-analysis and review. *Neuroscience and Biobehavioral Reviews*, *84*(2), 225–244. https://doi.org/10.1016/j.neubiorev.2017.11.020

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