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► **To cite this version:**

Cédric T. Albinet, Benoît Valéry, Mickael Causse. Inhibition control and cardiac reactivity in young and middle-aged adults. *Biological Psychology*, 2025, 201, pp.109139. <10.1016/j.biopsycho.2025.109139>. <hal-05335605>

HAL Id: hal-05335605

<https://hal.science/hal-05335605v1>

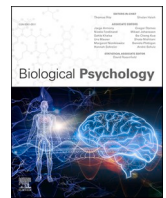
Submitted on 28 Oct 2025

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Inhibition control and cardiac reactivity in young and middle-aged adults

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ARTICLE INFO

Keywords:

Pre-Ejection Period
Inhibition control
Aging
Temporal dynamics
Habituation
Sensitization

ABSTRACT

This study investigated the dynamics of cardiac reactivity during the performance of three cognitive tasks involving various levels of inhibition control in young and middle-aged adults. Twenty-eight young adults (18–27 years) and twenty-two middle-aged adults (55–65 years) performed variations of a flanker task involving neutral, congruent, incongruent and No-Go trials, while their cardiovascular parameters (heart rate, blood pressure, cardiac Pre-Ejection Period: PEP) were recorded. Specifically, each task was repeated twice and we examined variations of PEP and PEP reactivity as a function of time on task and task repetition. The results revealed that PEP reactivity was shown to be a transient phenomenon, decreasing both over the course of each task (only significant during the first minute) and across repeated sessions. PEP reactivity was related to cognitive load, albeit not in a linear fashion, but was not clearly related to cognitive performance. Age-related effects were demonstrated for cognitive performance as well as resting and task PEP values, but not for PEP reactivity. It is concluded that PEP reactivity showed characteristics of habituation and sensitization that are discussed in light of the theory of dual-process habituation and the model of effort and cardiovascular response.

1. Introduction

Understanding and anticipating cognitive load or cognitive incapacitation is crucial for optimizing mental functioning at work and in everyday life, as well as in clinical settings. However, behavioral analysis alone often lacks the precision needed to fully understand or anticipate these phenomena. Consequently, researchers have long sought alternative indicators, with physiological measures emerging as a promising avenue. Mental effort is the mobilization of (cognitive) resources to carry out instrumental behavior (Gendolla, 2025; Gendolla et al., 2019). It is known to stimulate the sympathetic branch of the autonomic nervous system (ANS) on the cardiovascular system (Gendolla et al., 2019; Obrist, 1976; Wright, 1996). In the last two decades, a growing body of research has investigated the extent to which cardiac pre-ejection period (PEP) can be a physiological marker of mental effort. PEP refers to the time interval between ventricular depolarization and the opening of the aortic valve, which initiates blood ejection from the left ventricle. It is an indicator of myocardial contractility and is currently considered the most reliable noninvasive index of β -adrenergic sympathetic activity in the heart (Berntson et al., 1994; Cacioppo et al., 1994; Kelsey, 2012; Krohova et al., 2017;

Mezzacappa et al., 1999). Building on Obrist's (1976) work on the psychophysiology of active coping and Brehm and Self's (1989) motivational intensity theory, Wright (1996) developed an influential framework suggesting that effort intensity is reflected in cardiovascular responses governed by the sympathetic nervous system (SNS). Within this framework, increases in effort are associated with enhanced β -adrenergic activity, leading to a shortening of PEP. PEP reactivity is defined and calculated as the difference between PEP measured during rest and during the performance of a given task. More negative PEP reactivity values indicate greater sympathetic activity and thus greater effort exertion. Since the development of this model, numerous studies from different laboratories have shown that manipulations of cognitive load, mental stress, mood, emotion, and task incentive value can all elicit measurable changes in PEP reactivity (for detailed reviews, see Albinet et al., 2024; Gendolla, 2025a; 2025b; Gendolla et al., 2019; Kelsey, 2012; Richter et al., 2016). As such, it seems conceivable that as a task requires more and more cognitive control it requires more and more effort to cope with its constraints, which can be measured by an increase in PEP reactivity.

Although the use of PEP as a direct physiological measure of effort exertion during cognitive activity has been the subject of multiple

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<https://doi.org/10.1016/j.biopsycho.2025.109139>

Received 15 May 2025; Received in revised form 10 October 2025; Accepted 15 October 2025

Available online 16 October 2025

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theoretical, methodological and empirical investigations, several critical questions remain unresolved, as pointed out in a recent review on this topic (Albinet et al., 2024). The present study addresses three of these questions: (1) What are the temporal dynamics of PEP reactivity? (2) Can PEP reactivity be effectively studied using a within-subjects design, and are the results comparable to those obtained from the more commonly used between-subjects design? (3) How do the effects of advancing age influence PEP and PEP reactivity in response to cognitively challenging situations?

The temporal dynamics of PEP, at rest and during task performance, are critically important for identifying how this measure evolves over time, whether in the short term (e.g., time on task) or across longer intervals (e.g., between tasks during a session). It remains unclear whether PEP and PEP reactivity values show physiological drift or attenuation over time, potentially reflecting habituation or adaptation processes. According to the dual-process theory (Groves & Thompson, 1970), cardiovascular reactivity should show processes of habituation (reduction in intensity with repeated stimulation) and sensitization (incremental intensity and then decay in response to novel, intense or significant stimulation). To date, few studies have examined this question, and the available results are either contradictory or lack sufficient information. In the abundant psychophysiological literature, PEP or PEP reactivity measures were most of the time reported as mean values computed on the entire performance periods (usually several minutes). Although the vast majority of these studies has found significant effects on PEP and PEP reactivity over the entire task periods, this precludes the possibility to examine whether cardiovascular reactivity in such contexts is stable during the entire stimulation period or diminishes as a function of time on task. In the short term, research indicates that catecholamine concentrations (adrenaline and noradrenaline) dissipate over about nine seconds, suggesting that sympathetic responses to isolated events may last up to this duration (Kuipers et al., 2017; Mokrane & Nadeau, 1998). During longer tasks, however, the temporal dynamics of PEP reactivity remain more complex. For example, although the bulk of studies using PEP as effort measure found effects for entire task periods, some studies measuring PEP reactivity during 4–5-min cognitive tasks, using 1-min averaging epochs, have reported that significant reactivity is limited to the very first minute of task engagement, with values returning to baseline level afterward (Framorando et al., 2023; Framorando & Gendolla, 2018b; Kelsey et al., 1999, 2004), which is consistent with the process of sensitization. At a larger temporal scale, some studies have reported possible habituation effects in PEP reactivity across repeated exposures to the same stressors or cognitive tasks (Brenner et al., 2005; Kelsey et al., 2000, 2004), whereas others did not (Plain et al., 2021). Somewhat related, research by Czarnek et al. (2021) on prolonged stimulation during a simulated rescue operation in virtual reality found that PEP typically returned to baseline within 1–2 min after the task completion. This finding suggests that task-related sympathetic activation dissipates rather quickly, and that inter-task intervals of at least one minute may be necessary to avoid the effect of the previous task on subsequent measurements. Globally, the available literature does not offer a clear picture of how resting PEP and PEP reactivity evolve over time, either within or across successive tasks.

Most of the recent studies in psychophysiology rely on a between-subjects design, leaving the intra-individual evolution of PEP across repeated measures of the same task underexplored. Moreover, PEP values exhibit significant interindividual variability, primarily due to factors such as age, sex, and health status (see Albinet et al., 2024). This variability makes the between-subjects design less suitable for studying this physiological measure effectively. To effectively use PEP and PEP reactivity as physiological indices of mental effort, it is important to unravel the effects of time-on-task, task difficulty and recovery time on the same individuals. Most of the few studies that have used a within-subjects design have reported results somewhat consistent with those using a between-subjects design (e.g., Cancela et al., 2023; Cancela & Silvestrini, 2021; Kelsey et al., 2007; Montoya et al., 1997; Plain et al.,

2021). However, these studies often failed to report needed details on the evolution of absolute PEP values during both resting and activity periods. As discussed in the preceding paragraph, this information is important to understand how PEP and PEP reactivity evolve over time, during and after a series of challenging tasks, task repetitions, or task difficulty levels. Such an examination is best carried out by a within-subjects design.

Finally, little is known about the effects of aging on PEP and PEP reactivity during cognitively challenging situations. Few studies examining this question were found, and their results are inconclusive. Cybulski (1996) did not find any significant effect of age on the mean resting state PEP among adults aged 22–59. On the other hand, Steptoe et al. (2005) and Gurel et al. (2019) reported shorter resting PEP values for older adults compared to younger adults and higher PEP recovery or PEP reactivity for the younger ones. This was agreed by a meta-analysis conducted by Brindle et al. (2014), according to which advancing in age (from 18 to 82) was associated with a decrease in sympathetic reactivity (notably PEP reactivity) under stress conditions. However, using various stress tasks and cardiovascular reactivity measures, Jennings et al. (1997) and Uchino et al. (1999) showed that an increase in age from 30 to 70 years was significantly associated with an increase in cardiovascular reactivity. However, confounding factors, such as variations in heart rate (HR), diastolic blood pressure (DBP), or medication, may have influenced some of the results (see Sherwood(Chair) et al., 1990), which justifies the need to examine more comprehensively the effects of advancing age on PEP and PEP reactivity.

The present study investigates cardiac reactivity—measured via PEP—during the performance of three cognitive tasks involving various levels of inhibition control in young and middle-aged adults. Adapted from the Eriksen flanker task (Eriksen & Eriksen, 1974), these tasks were designed to assess both cognitive performance variations and physiological responses under conditions requiring either no or minimal executive control, interference control ability, or interference control ability and response inhibition, using a mixed design. It was hypothesized that the difficulty and cognitive load of these three tasks would increase as a function of the level of inhibition control required, necessitating more and more effort for their successful execution. Accordingly, at a behavioral level, cognitive performance should decrease and, at a physiological level, SNS activity should increase, as measured by higher PEP reactivity. Based on Groves and Thompson's dual-process theory (1970), we also hypothesized that PEP reactivity should be more important the first time a given task is performed and during the first minute of its realization. Finally, we also hypothesized that cognitive performance should be lower for the middle-aged group than the younger adult group. Given the contradictory results of the literature concerning the measures of PEP and PEP reactivity as a function of age, we adopted an exploratory strategy with no a priori hypothesis.

2. Materials and methods

2.1. Participants

Thirty young adults (18–27 years; $M = 20.2$ years, $SD = 2.3$, 15 females) and thirty middle-aged adults (55–65 years; $M = 60.9$ years, $SD = 3.2$, 16 females) participated in the study and received a compensation of 10€. Most of the young adults were students at the University Champollion of Albi. The middle-aged participants were recruited through advertisements placed on social and professional networks, as well as with businesses and various public and private institutions in the community. All the participants reported no neurological or cardiovascular disorder. They all had normal or corrected vision. The sample size was estimated based on the effects sizes reported in the literature and particularly the meta-analysis of Brindle et al. (2014), which reported a general medium effect size for PEP (Hedge's $g = -0.58$). With alpha set at 5% and the power at 80%, the total sample size was estimated at 50

participants. Seven participants were excluded from the analysis due to poor physiological signal quality or incomplete recording. Three other participants were excluded because they were outliers based on cardiac or behavioral measures. The final sample of participants comprised twenty-eight young adults ($M = 20.3$ years, $SD = 2.4$, 14 females) and twenty-two older adults ($M = 60.2$ years, $SD = 3.5$, 11 females). They all gave their written informed consent at the beginning of the study, which was approved by the local ethics committee (IRB - N° 00011835–2021–0928–418) and complied with the Declaration of Helsinki for human experimentation.

2.2. Task and procedure

The protocol took place in a single session in a quiet experimental room. Before starting the protocol, the participants read an information notice that specified the objective of the study. After checking the inclusion and exclusion criteria (no smoking or drinking coffee in the last two hours, no cardiac, neurological or psychiatric disorders), they signed the consent form. Then, they completed a sociodemographic information form (age, sex, weight, height, profession and highest level of education). Cardiovascular indices (see below) were recorded during a first resting period of 5 min.

This initial 5-min resting period was intended to provide cardiovascular baseline measures. However, a preliminary analysis revealed that resting PEP values at the end of this resting period were systematically shorter than during subsequent 3-min resting periods, and also than during all the task periods. The cardiovascular indices during the last 2-min of this initial 5-min period are shown in the appendix Table A1. This pattern was interpreted as indicating higher cardiac sympathetic activity linked with an increased anxiety related to the still unfamiliar laboratory environment and a possible white coat effect (see Thorson et al., 2020). Consequently, as detailed below, we chose to rely on the 3-min resting periods recorded immediately before each task, as they were less influenced by the initial anxiety, and more accurately reflected the participants' resting state just prior to task onset. Indeed, employing multiple baselines within a single session helps to minimize natural physiological drift and to limit the carryover of responses from one task to subsequent ones (Jennings et al., 1992). This solution is relevant in experiments such as ours, where several blocks of different task conditions are presented in succession (see Kelsey et al., 1999; 2000; 2004 for a similar procedure). After this initial resting period, participants had to train (with feedback on their performance) and then practiced the cognitive task (without feedback on their performance).

2.2.1. Cognitive/flanker task

The cognitive task was a modified version of the Eriksen flanker task

(Eriksen & Eriksen, 1974; Heil et al., 2000) incorporating neutral, congruent, and incongruent conditions, along with Go (response required) and No-Go (response inhibition) trials. The task was presented on a computer screen, and participants responded by pressing either the left or right key on a Cedrus RB-740 response box. They were instructed to respond as quickly as possible without making an error to a central target arrow, indicating its direction (< or >) while ignoring flanking stimuli. These flankers consisted of arrows pointing in either the same or opposite direction (>> or <<), or □□ for the neutral condition. As depicted in Fig. 1, the task was organized around three experimental blocks. The first block, the neutral block, involving only neutral trials (e.g., □□<□□), corresponded to a choice reaction time task involving no or very little executive control. A second block, the flanker block, corresponded to the classic flanker task with congruent trials (e.g., <<<<<, 50 %) and incongruent trials (e.g., <<><<, 50 %). This condition made it possible to assess interference control ability (inhibition of irrelevant information) by comparing performance on incongruent trials with congruent trials. A third block, the flanker no-go block, corresponded to the modified flanker task with additional Go trials (70 %) and No-Go trials (30 %) depending on the nature of a preparatory signal. Each trial was preceded by a preparatory signal (—), which could be the same color as the target (Go trial) or a different color (No-Go trial). The colors red and green were used. This condition made it possible to evaluate not only the interference control ability but also the response inhibition ability during No-Go trials, which required stopping the response normally expected. Thus, these three blocks differed in the amount of inhibitory control necessary for their successful execution. Each block lasted approximately 4 min and 30 s and was repeated twice (session 1 - session 2). During each individual block, 40 trials were presented, for a total of 80 trials across the two sessions. Each trial consisted of a fixation cross presented for 250 ms, followed by the preparatory signal presented for 500 ms. This was followed by a series of arrows presented until the response, or for 2000 ms in the absence of response. Finally, a black screen was presented during the inter-stimulus interval, with a jitter period of randomized durations between 2000 and 6000 ms. The order of presentation of the blocks was counterbalanced between the participants. Before each given task, both its name and its specific instructions were displayed on the computer screen. The participants were not instructed about the different difficulties of each task. Before each block, there was a 3-min rest period to ensure a return to the baseline level of cardiac activity (Czarnek et al., 2021). Thus, there were six resting periods. At the end of the final cognitive task, a final 3-min rest period was recorded as a recovery period. We recorded the proportion of correct responses (CR) as % and response time (RT) in ms. The first two trials of each block were excluded from the analyses. Because significant differences typically are

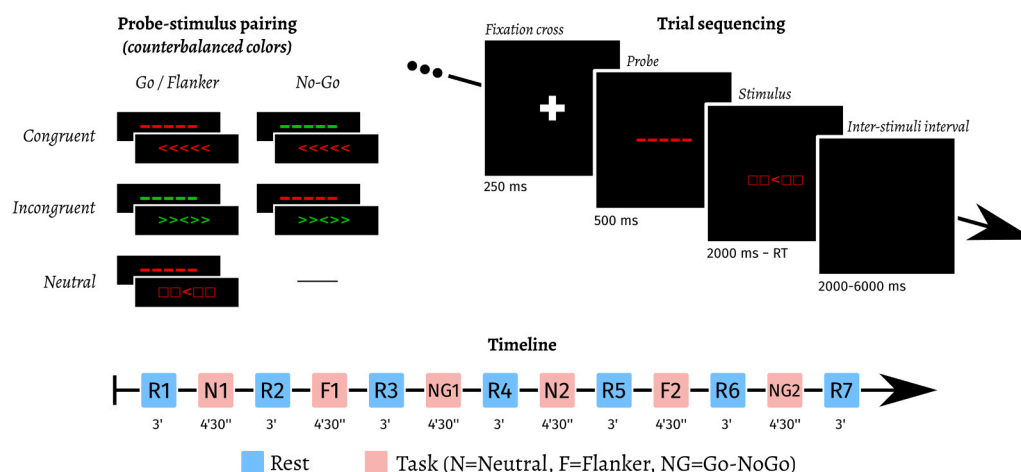


Fig. 1. Schema of the experimental and trial procedure.

seen between young and older adults in accuracy and response speed as well as in the speed-accuracy tradeoff (older adults often favor accuracy over speed, whereas younger adults favor speed), we computed a classic composite performance score as the dependent variable for the performance on this task, calculated as: $CR/RT \times 100$. The higher this score, the greater the performance.

2.2.2. Physiological measurements

Cardiac activity was recorded using the BIOPAC MP160 system at an acquisition frequency of 2000 Hz. The electrocardiogram (ECG) and impedance cardiogram (ICG) electrodes were placed on the neck and torso of the participant following the recommendations (Sherwood (Chair) et al., 1990). For the ECG, one electrode was placed under each clavicle, and the third was placed at two fingers below the floating ribs on the left side. For the ICG, four pairs of electrodes were placed on the right and left sides of the base of the participant's neck and on the left and right middle axillary line at the height of the xiphoid. An Omron Carescape V100 monitor was used to record systolic and diastolic blood pressure (SBP and DBP) during each rest period. These measurements were used to monitor changes in BP and HR for accurate interpretation of ECG/ICG signals. Notably, PEP reduction reflects increases in β -adrenergic activity only when HR and BP are stable or rising (Krohova et al., 2017; Sherwood(Chair) et al., 1990).

2.3. Signal analysis and statistical analysis

Cardiovascular data were processed in MATLAB using PEPAnalyzer, a user-friendly software developed by the Sciences of Cognition, Technology and Ergonomics (SCoTE) Laboratory. This tool is based on the algorithm developed by Forouzanfar et al. (2018) and is designed for ECG/ICG signal analysis. On the ECG, for each cardiac cycle, R-peak was detected using the function *findpeaks* available in MATLAB. The Q-point (R-onset) was detected as the last point before the ECG R-peak where the slope falls below a threshold set to $-1.2 \times R\text{-peak} \div fs$, where fs is the ECG sampling frequency and R-peak is the R-peak amplitude. The B-point was searched within the most prominent monotonically increasing segment of the dZ/dt signal on the ICG limited between the local minimum of dZ/dt signal that occurred before its rapid rise (A-point) and the dZ/dt maximum (C-point). The B-point was then localized by Fourouzanfar et al.'s (2018) step-by-step algorithm. As suggested by these authors, some noise or movement artifacts can still cause few incorrect detections or placements of the B-point. As such, we then followed their "Step 2: Correction" procedure to further identify and correct the B-points that occurred too early or too late compared to the rest of the data points. The procedure was strictly identical to that of Forouzanfar et al. (2018), except for step 4, where we corrected the outlier values using the mean of the four values flanking the outlier. PEP was defined as the time interval between the R-onset (Q point on the ECG signal) and the B-point on the dZ/dt waveform of the ICG signal (Sherwood(Chair) et al., 1990). All PEP < 40 ms or > 200 ms were automatically excluded and those differing for two standard deviations or more were labeled for visual inspection of the ECG/ICG signals, and when appropriate were discarded. This represented 5.18 % of the total PEP values. PEP values were averaged over 1-min epochs. Resting PEP was found to be stable across three such epochs during the resting periods, so the mean of these three was used for each rest period. To examine the temporal dynamics of cardiac activity during the task blocks, mean PEP was also calculated for each of four successive 1-min epochs (labeled hereafter Window 1, Window 2, Window 3, Window 4). The primary dependent variables were mean PEP in ms and PEP reactivity (Δ PEP) in ms, calculated as task PEP minus resting PEP from the immediately preceding resting period (e.g., for task F1 in Fig. 1, resting PEP of R2 was subtracted to task F1 PEP). The more negative Δ PEP, the stronger PEP reactivity.

To analyze the cognitive, PEP and PEP reactivity data, linear mixed-effects models (LMMs) were employed using restricted maximum

likelihood (REML). LMMs were chosen due to their ability to account for the hierarchical structure of the data (i.e., repeated measures nested within subjects), as recommended in the multilevel modeling literature (Burnham & Anderson, 2002; Gelman & Hill, 2007). Participants were treated as a random intercept to control for individual variability. For the cognitive data, fixed effects included the within-subject factors Session (2 levels) and Task (3 levels), as well as the between-subject factor Group (2 levels). We hypothesized that cognitive performance should decrease from the neutral task to the flanker task and further decline in the flanker No-Go task, and that younger adults would demonstrate better performance than the middle-aged adults. For PEP and PEP reactivity data, fixed effects included the within-subject factors Session (2 levels), Task (3 levels), and Window (4 levels), as well as the between-subject factor Group (2 levels). We hypothesized that during task performance, PEP reactivity should be stronger (more negative PEP reactivity values) during the first session than during the second session, be stronger for the flanker No-Go than for the flanker task and stronger for the flanker task compared to the neutral task, and should decrease for each task as a function of time on task (i.e., from Window 1 to Window 4). The fourth order interaction between these factors was further introduced to assess whether it improved model fit. Model comparison was performed using the Akaike Information Criterion (AIC) to evaluate whether the inclusion of this higher-order interaction significantly improved model fit (Burnham & Anderson, 2002). As presented in the Results section, although the higher-order interaction reached statistical significance ($p = .007$), it substantially increased AIC value, and thus decreased the overall model parsimony. According to the principle of model parsimony and information-theoretic model selection (Burnham & Anderson, 2002), this non-contributive interaction was excluded from the final model. Furthermore, the risk of overfitting and the known difficulty of detecting interaction effects in psychological data (McClelland & Judd, 1993) guided our decision to prioritize simpler models when appropriate. Initial analyses of the main effects corresponding to our hypotheses were used to explore general patterns before estimating more complex models including the full interaction structure for PEP reactivity.

To examine whether PEP reactivity at each minute during tasks performance (Windows 1–4) was significantly different from 0, multiple t tests against 0 (corrected for multiple comparisons) were performed.

To analyze the HR, SBP and DBP data at rest, separate mixed-design ANOVAs were conducted for each measure, with Group (young vs. middle-aged) as the between-subjects factor and Resting session (1–6) as the within-subjects factor. When sphericity assumptions were violated, degrees of freedom were adjusted using the Greenhouse-Geisser correction. It was hypothesized that these cardiovascular indices should remain stable across these six sessions.

Finally, to explore the relationship between PEP reactivity and task cognitive performance, we conducted a series of bivariate correlations (Pearson's product-moment correlations) separately for each participant group.

Results are reported as means (M) with 95 % confidence intervals in brackets, and statistical significance was set at $p \leq .05$. When appropriate for significant effects, estimated effect sizes are reported as partial eta square (η_p^2) or Cohen's d . Effect sizes were interpreted as follows: small ($\eta_p^2 < .01$ or Cohen's $d < 0.2$), medium ($\eta_p^2 < .06$ or Cohen's $d < 0.5$), and large ($\eta_p^2 > .14$ or Cohen's $d > 0.8$). Post-hoc analyses were conducted using the Bonferroni correction.

3. Results

3.1. Physiological measures

3.1.1. Heart Rate (HR) and Blood Pressure (BP) during resting periods

Table 1 reports SBP, DBP and HR during the six resting periods for both age groups. For SBP, the analysis revealed a significant main effect of group, $F(1,48) = 6.65$; $p = .013$; $\eta_p^2 = .122$, with the middle-aged

Table 1

Mean values (standard deviation) of cardiovascular indices as a function of resting period for the young and middle-aged adult groups.

		Resting periods						
		1	2	3	4	5	6	
Young adults	HR (bpm)	79.3 (9)	80.5 (10)	80 (9)	80.6 (10)	79.3 (9)	80.2 (10)	
	SBP (mmHg)	114 (9)	113 (9)	113 (10)	112 (11)	110 (8)	111 (8)	
	DBP (mmHg)	65.2 (6)	62.8 (6)	63 (7)	64.2 (9)	63.4 (6)	64.5 (8)	
	PEP (ms)	111 (17.6)	112 (18.5)	113 (17.8)	115 (17.4)	116 (17.2)	115 (15.8)	
	Middle-aged adults	HR (bpm)	71.8 (7)	70.7 (8)	71.9 (7)	71.7 (8)	72 (7)	71 (7)
		SBP (mmHg)	122 (18)	118 (14)	120 (14)	119 (14)	120 (15)	121 (15)
DBP (mmHg)		71.5 (9)	71.5 (9)	72.2 (10)	72.3 (9)	72.9 (9)	73.8 (9)	
PEP (ms)		124 (15.1)	125 (15.6)	125 (16.1)	125 (15.2)	127 (15.4)	127 (13.8)	

HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure; PEP = Pre-ejection Period

group demonstrating higher SBP values ($M = 120$ mmHg [116–125]) than the young adult group ($M = 112$ mmHg [108–116]). No other effect reached statistical significance.

For DBP, a significant main effect of group was again observed, $F(1,48) = 16.3$; $p < .001$; $\eta_p^2 = .235$, with middle-aged adults having higher DBP ($M = 72.4$ mmHg [69.2–75.5]) than young adults ($M = 63.8$ mmHg [61–66.7]). There was a trend for a significant main effect of resting session, $F(5240) = 2.35$; $p = .054$; $\eta_p^2 = .047$; Greenhouse-Geisser $\epsilon = 0.825$.

For HR, the analysis revealed a significant main effect of group, $F(1,48) = 12.5$; $p < .001$; $\eta_p^2 = .207$, with the middle-aged group having lower HR values ($M = 71.5$ bpm [67.9–75.1]) compared to the young adult group ($M = 80$ bpm [76.8–83.2]). There was also a significant Group \times Resting session interaction, $F(5240) = 2.71$, $p = .035$; $\eta_p^2 = .053$, Greenhouse-Geisser $\epsilon = 0.746$. In none of the age groups did HR change significantly as a function of the resting sessions (all $ps > .05$).

3.1.2. Absolute Pre-Ejection Period (PEP)

3.1.2.1. Resting PEP. As detailed in 2.2.1., participants completed a 3-min resting period before each cognitive task block. The MLM from the fixed effects of Group (2 levels), Session (2 levels) and Task (3 levels), with random intercepts for participants (ID) to account for repeated measures converged successfully. It demonstrated adequate fit (AIC = 1812.69; log-likelihood = -895.13). The marginal R^2 (variance explained by fixed effects only) was.119, while the conditional R^2 (variance explained by both fixed and random effects) was.966. Omnibus F-tests for fixed effects revealed a significant main effect of group, $F(1, 48) = 6.63$, $p = .013$, with middle-aged participants showing longer resting PEP ($M = 126$ ms [119–133]) than young participants ($M = 114$ ms [108–120]). There was also a significant main effect of session, $F(1, 247) = 46.36$, $p < .001$, with PEP being longer in Session 2 ($M = 121$ ms [116–125]) compared to Session 1 ($M = 118$ ms [114–123]). The main effect of Task did not reach statistical significance, $F(2, 247) = 2.39$, $p = .094$. Table 2 reports resting PEP values as a function of task and session for both age groups.

3.1.2.2. Task PEP. As detailed in 2.2.1., task-related PEP was averaged over four 1-min epochs per task. The MLM from the fixed effects of Group (2 levels), Session (2 levels), Task (3 levels), and Window (4 levels), with random intercepts for participants (ID) to account for repeated measures converged successfully. It demonstrated adequate fit (AIC = 7308.466; log-likelihood = -3640.722). The marginal R^2

Table 2

Mean values (standard deviation) of resting PEP in ms as a function of task and session for the young and middle-aged adult groups.

	Task					
	neutral		flanker		flanker No-Go	
	Session 1	Session 2	Session 1	Session 2	Session 1	Session 2
Young adults	112 (19)	115 (16.7)	111 (18.2)	115 (16.5)	113 (16.7)	116 (17.1)
Middle-aged adults	125 (16.1)	126 (14.2)	124 (15.2)	126 (15.7)	125 (15.6)	127 (14.6)

was.121, while the conditional R^2 was.935. Omnibus F-tests for fixed effects revealed a significant main effect of group, $F(1, 48) = 6.25$, $p = .016$, with middle-aged participants showing longer task PEP values ($M = 125$ ms [118–132]) than young participants ($M = 113$ ms [107–119]). There was also a significant main effect of session, $F(1, 1144) = 200.78$, $p < .001$, with longer task PEP in Session 2 ($M = 121$ ms [116–125]) than in Session 1 ($M = 117$ ms [112–122]). Finally and importantly, a significant effect of window was found, $F(3, 1144) = 48.52$; $p < .001$. PEP during the first 1-min window ($M = 116$ ms [112–121]) was significantly shorter than in windows 2–4 ($M = 120$ ms [115–125]), which did not differ from each other. Table 3 reports task PEP and HR values as a function of task and session for both age groups.

3.1.3. PEP reactivity

Fig. 2 illustrates mean PEP reactivity by group as a function of session, task and window. The MLM from the fixed effects of Group (2 levels), Session (2 levels), Task (3 levels), and Window (4 levels), with random intercepts for participants (ID) to account for repeated measures converged successfully. It demonstrated adequate fit (AIC = 7102.991; log-likelihood = -3542.433). The marginal R^2 was.010, while the conditional R^2 was.365. Omnibus F-tests for fixed effects revealed a significant main effect of session, $F(1, 1144) = 20.17$, $p < .001$, indicating that overall PEP reactivity was stronger in Session 1 ($M = -1.2$ ms [-2.1–0.3]) compared to Session 2 ($M = -0.05$ ms [-1.1–1.0]). The results also showed a main effect of task, $F(2, 1144) = 6.57$, $p = .001$, which demonstrates greater PEP reactivity during the flanker No-Go task ($M = -1.3$ ms [-2.2–0.4]) compared to the flanker task ($M = -0.3$ ms [-1.2–0.6]) and the neutral task ($M = -0.4$ ms [-1.3–0.5]), which did not differ from each other. The significant main effect of window was found, $F(3, 1144) = 50.15$, $p < .001$, with greater PEP reactivity during the first 1-min window ($M = -3.4$ ms [-4.3–2.4]) compared to windows 2–4, which did not differ from each other (M range 0–0.4 ms). Multiple tests against 0 with correction for multiple comparisons showed that PEP reactivity was significantly different from 0 only during the first 1-min window of each task and for each session, except for the neutral task at session 2 ($ts < -3.18$, $ps < .001$, Cohen's d s ranged from -0.45 to -0.78). Finally, the main effect of group was not significant ($F(1,48) = 0.362$).

As explained in 2.3, we then introduced in this model the fourth level interaction involving the factors Group (2 levels) \times Session (2 levels) \times Task (3 levels) \times Window (4 levels), to exploratory examine whether they interact, particularly as a function of participants' age group. Although the model showed a significant Group \times Session \times Task \times Window interaction, $F(40, 1087) = 1.65$, $p = .007$, the model fit decreased with an AIC value of 7134.973 and a log-likelihood value of -3477.38. Accordingly, this interaction was excluded from the final model.

3.2. Cognitive performance

The MLM from the fixed effects of Group (2 levels), Session (2 levels)

Table 3

Mean values (standard deviation) of task PEP (ms) and HR (bpm) as a function of task and session for the young and middle-aged adult groups.

		Task					
		neutral		flanker		flanker No-Go	
		Session 1	Session 2	Session 1	Session 2	Session 1	Session 2
Young adults	HR (bpm)	80 (10)	80 (10)	80 (10)	80 (11)	81 (10)	79 (9)
	PEP (ms)	111 (19.5)	116 (16.7)	112 (17.4)	115 (16.6)	111 (17.6)	115 (16.7)
Middle-aged adults	HR (bpm)	72 (8)	71 (7)	73 (8)	71(9)	73 (8)	71 (8)
	PEP (ms)	123 (15.3)	128 (14.3)	123 (15.5)	125 (15.3)	123 (16)	126 (13.2)

HR = heart rate; PEP = pre-ejection period

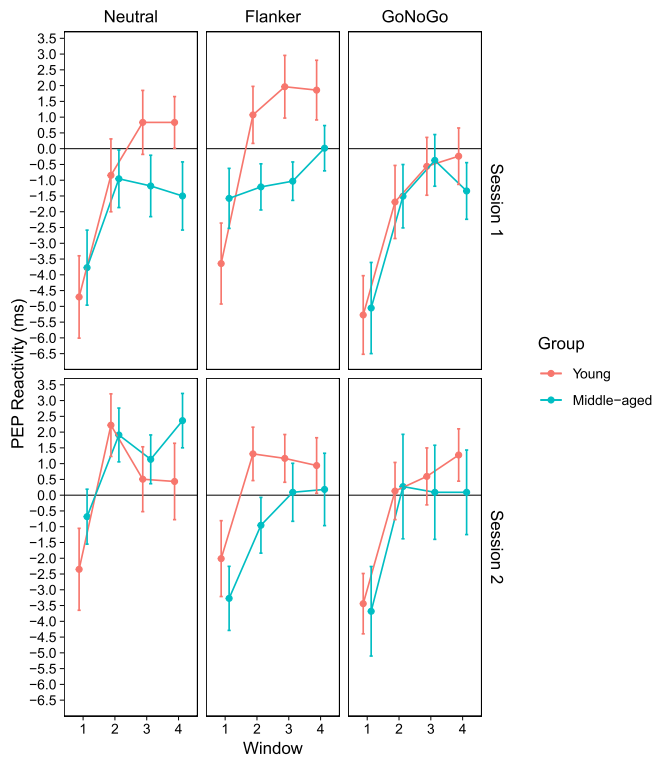


Fig. 2. Mean values of PEP reactivity for the young adults (red) and middle-aged adults (blue) as a function of task (neutral-flanker-flanker No-Go), window (1–4) and session (1–2). Bars represent standard error.

and Task (3 levels), with random intercepts for participants (ID) to account for repeated measures converged successfully. It demonstrated adequate fit (AIC = 1211.982; log-likelihood = -601.01). The marginal R^2 was .579, while the conditional R^2 was .886. Omnibus F-tests for fixed effects revealed a significant main effect of task ($F(2,247) = 369.62$; $p < .001$), with the composite performance scores significantly decreasing from the neutral block ($M = 23.3$ [22.5–24.2]) to the flanker block ($M = 19.5$ [18.8–20.1]) and further to the flanker No-Go block ($M = 18.1$ [17.4–18.8]). A significant main effect of group was also found, $F(1,48) = 45.14$; $p < .001$, with young adults scoring higher overall ($M = 22.3$ [21.4–23.2]) than middle-aged adults ($M = 17.7$ [16.7–18.8]). Finally, performance significantly increased from session 1 to session 2, $F(1,247) = 7.37$; $p = .007$, with score increasing from $M = 20.1$ [19.2–20.8] to $M = 20.5$ [19.9–21.2]. Fig. 3 illustrates these results.

3.3. Relationship between cognitive performance and PEP reactivity

To explore the relationship between autonomic reactivity and task performance, we conducted a series of bivariate correlations separately for each participant group. We examined the association between the composite cognitive performance scores and PEP reactivity during the

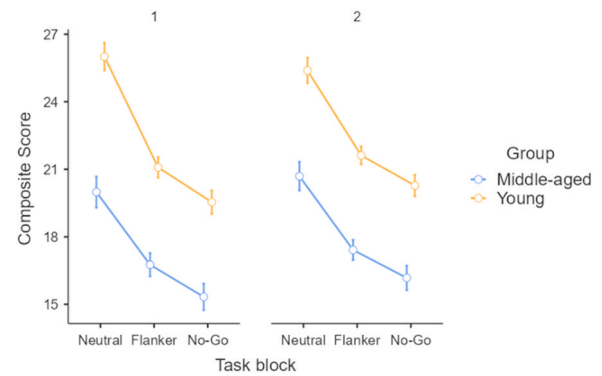


Fig. 3. Mean of composite performance scores for the young adults (yellow) and middle-aged adults (blue) as a function of task (neutral-flanker-flanker No-Go) and session (1–2). Bars represent standard error.

first 1-min window for each task and session. For the middle-aged group, the results revealed a significant negative correlation between cognitive performance and PEP reactivity for the neutral task during Session 1 ($r(22) = -.45$; $p < .05$) and a significant positive correlation during the Session 2 ($r(22) = .44$; $p < .05$). These results suggest that a higher PEP reactivity during the first minute of the first session of this task was related to a better cognitive performance for these participants, whereas during the second session, a lower PEP reactivity was related to better performance. No significant correlation emerged for the two other tasks (all $ps > .1$; correlation coefficients ranged from .25 to .30).

For the young group, no significant correlations emerged regardless of the task or session (all $ps > .2$; correlation coefficients ranged from $-.24$ to .23).

4. Discussion

This study used a mixed design to examine the temporal dynamics of resting PEP, task PEP and PEP reactivity as a function of cognitive load in young and middle-aged adults. We hypothesized that (1) PEP reactivity would increase with cognitive load, (2) decrease over time on task and (3) diminish with the repetition of the same task. We also hypothesized that middle-aged adults would demonstrate lower cognitive performance and we explored how their cardiovascular reactivity evolved as a function of these factors compared to the young adults. The main findings revealed that PEP reactivity was shown to be a transient phenomenon, decreasing both over the course of each task and across repeated sessions. PEP reactivity was somewhat related to cognitive load, albeit not in a linear fashion, but was not clearly related to cognitive performance. Age-related effects were demonstrated for cognitive performance as well as resting and task PEP values, but not for PEP reactivity. Importantly, the lack of significant decreases in DBP and HR supports the interpretation that PEP variations were driven by sympathetic nervous system activity rather than changes in overall cardiovascular tone (Krohova et al., 2017; Sherwood(Chair) et al., 1990).

4.1. Temporal dynamics of PEP and PEP reactivity

In the present study, both resting and task-related absolute PEP values increased as a function of repetition of the same condition, as evidenced by longer PEP durations in Session 2 than in Session 1. These results support the value of using resting periods immediately preceding each task as baselines. This design allows for the comparison of PEP values between each task and its corresponding baseline, more accurately capturing immediate PEP variations relative to the participant's current physiological state than comparisons with a single resting period recorded several minutes earlier. Consistently, PEP reactivity decreased as a function of task repetition, suggesting a modulation of sympathetic nervous system activity over time. Moreover, during task performance, both absolute PEP and PEP reactivity were sensitive to time on task. Absolute PEP was significantly shorter during the first minute and PEP reactivity was significant only during this first minute. These findings align with the work of Kelsey and colleagues (1999, 2000, 2004), that cardiac reactivity declines with task repetition, suggesting a general reduction in β -adrenergic sympathetic activity with repeated exposure to the same stressor or constraint. In various contexts using mental arithmetic tasks and stress conditions, Kelsey et al. observed that cardiac reactivity reduced when confronted several times with the same task or condition, consistent with a process of habituation (Groves & Thompson, 1970). PEP reactivity also peaked during the first minute of each cognitive task and then went back toward baseline level, showing a somewhat rapid reduction in β -adrenergic sympathetic activity with time on task. Similar results have previously been reported but few have been discussed by other teams (Framorando et al., 2023; Framorando & Gendolla, 2018a; Kelsey et al., 1999; 2004) in different cognitive and stress contexts. It is important to remember that in our study, although PEP reactivity during the first minute of each task block was reduced during the second session, it remained significantly different from zero (except for the second session of the neutral task). This may reflect a process of sensitization, that is, the system activation by novel, intense or significant stimulation, as proposed by the dual process theory of habituation (Groves & Thompson, 1970; see Kelsey et al., 2000, 2004 for a discussion). To conclude on this point, although cardiac reactivity reduced after the first minute during the realization of a cognitive task and when the task was repeated, cognitive performance was maintained, even improved over time. The reduction in cardiac reactivity may thus reflect an active process of adaptation rather than a passive process of fatigue or withdrawal. But if PEP reactivity is a physiological indicator of effort intensity as proposed by Wright (1996), our data could imply that effort to cope with task constraints is limited to the very first minute of the task, while cognitive performance is maintained. An alternative explanation could be an overactivation of the SNS just at the start of the challenging task, which reduces with task familiarization. This latter explanation is consistent with Obrist's (1981) and Sherwood et al.'s (1986) observations that cardiovascular responses can exceed bodily metabolic demands during psychological stress. A reasonable explanation for this phenomenon is that the body is preparing for the possibility of metabolically demanding physical activity, even if none is required at the moment (see Seery, 2011). We will revisit this controversy in 4.4.

4.2. PEP reactivity, cognitive load and cognitive performance

Cognitive performance decreased as a function of the level of inhibition control required in the tasks. This finding confirms that we successfully manipulated cognitive load and validates our behavioral hypothesis. As expected, cognitive performance measured in terms of both speed and accuracy was lowest in tasks requiring greater inhibition control. This is consistent with the literature (Verbruggen et al., 2004). Cognitive performance slightly improved from Session 1 to Session 2, suggesting that participants' investment was maintained even in the face of task repetition, or a form of learning effect. PEP reactivity, at least during the first minute of each cognitive task, was significantly greater

during the most challenging situation—the flanker No-Go task, which involved both interference control and response inhibition. The two other tasks did not significantly differ from each other. This result gives partial support to our hypothesis and to the model of effort and cardiovascular response developed by Wright (1996), and adds to the growing literature on this topic (see Albinet et al., 2024; Gendolla, 2025ab; Gendolla et al., 2019; Richter et al., 2016 for reviews). However, the relationship between PEP reactivity and cognitive load showed only a moderate effect size and was not linear as proposed by Wright's model. Indeed, PEP reactivity was equivalent during the neutral task, requiring minimal, if any, executive control, and during the flanker task, which required interference control ability. If PEP responds proportionally to an individual's effort engagement due to task difficulty, we should have shown significant differences between these two conditions. Such a nonlinear relationship between PEP reactivity and task difficulty has already been reported in the literature (Mallat et al., 2020; Silvestrini & Gendolla, 2013). More work is needed to clarify if these discrepancies come from divergences in the definition and manipulation of task difficulty (see 4.5), from certain moderators involved in the task difficulty and PEP relationship, or from a need to refresh the theoretical model.

The relationship between cognitive performance and PEP reactivity was inconsistent and difficult to interpret. First, for the young adults, there were no significant correlations between cognitive performance and PEP reactivity. Second, for the middle-aged group, significant correlations were only observed on the easiest neutral task. Third, these correlations between cognitive performance and PEP reactivity were negative during the first session and positive during the second session. These contradictory results suggest that a higher PEP reactivity during the first minute of the first session of this task was related to a better cognitive performance for these participants. In contrast, during the second session, lower PEP reactivity was related to better performance. Given these discrepancies, a true relationship between cognitive performance and PEP reactivity is questionable. Although cardiac reactivity may be a measure of effort exertion or task engagement, it does not consistently predict cognitive or behavioral performance in the literature (see Albinet et al., 2024; Gendolla, 2025a; Seery, 2011). As stated by Gendolla (2025a), “even if effort can contribute to performance, drawing conclusions about effort exertion based on performance is hardly warranted.” (p. 5)

4.3. Effects of age

Age-related differences emerged in both cognitive performance and physiological markers. Considering both speed and accuracy, our results showed that middle-aged participants performed worse during all the cognitive tasks compared to the young adults. This result is consistent with several previous studies using similar material (e.g., Salthouse, 2010), even though a recent meta-analysis concluded that the age-related effects are more important in Go-NoGo tasks than in flanker tasks (Rey-Mermet & Gade, 2018).

Concerning the physiological measures, our study provides interesting new findings. Middle-aged participants exhibited higher values of resting SBP and DBP and lower values of HR compared to their younger counterparts, consistent with previous reports (e.g., Franklin et al., 1997). They also demonstrated higher PEP values, both at rest and during cognitive performance. However, we did not find a significant age-related difference in PEP reactivity. This would indicate a decrease in the SNS activity level in the middle-aged adults, but not reduced cardiac reactivity. These results diverge from most of those in the literature reported in the Introduction section; the general assumption is that aging is characterized by an increase in SNS activity in several peripheral tissues, including the heart (Seals & Dinunno, 2004). More specifically, Uchino et al. (1999) showed no age-related difference in resting PEP in a sample of 30–70-year-olds. Their study and one by Jennings et al. (1997) have shown that PEP reactivity is more important

in older adults than in young adults. On the contrary, the meta-analysis conducted by Brindle et al. (2014) showed that advancing in age was associated with a global decrease in PEP reactivity under various stress conditions. Differences in the samples' characteristics and the experimental methodologies may partly explain these discrepancies. Still, it is difficult to fully compare these studies with the present one because they failed to report all the cardiovascular raw data. In our study, using repeated measures and considering potential confounding factors (resting HR, SBP, DBP), we consistently showed a moderate to strong effect of age on resting and task PEP, but no effect of age on PEP reactivity. It may be that our sample of middle-aged adults (55–65 years) is not characteristic of the older aging population targeted by the studies on aging. Clearly, more work is still needed, using a lifespan perspective, to more fully understand the effect of advancing age on these issues. For instance, although exploratory and not sufficiently fitting, our second MLM on PEP reactivity data showed that age might have complex effects on PEP reactivity dynamics as a function of task, time on task and session.

4.4. Theoretical interpretation and implications

The temporal dynamics of PEP and PEP reactivity observed in this study align well with the dual-process theory of habituation proposed by Groves and Thompson (1970). The decline in PEP reactivity across repeated task sessions suggests a process of habituation, while the consistent elevation of PEP reactivity during the first minute of each cognitive task points to a process of sensitization. According to the dual-process theory, these two processes are independent but interact to produce the final observable physiological response. In our data, PEP reactivity decreased (habituated) as a function of task repetition, but still remained significant (sensitive) at the beginning of each task. The effect of task difficulty, while in the expected direction, is less consistent with the dual-process theory and the model of effort and cardiovascular response proposed by Wright (1996). Indeed, suppose an increase in task difficulty involves increased mental effort. In that case, we should have seen a somewhat proportional increase in PEP reactivity, which was not the case between the neutral task and the flanker task. Of importance, as well discussed by authoritative papers on the motivational intensity theory (Gendolla, 2025a; Gendolla et al., 2019, Richter et al., 2016), variables other than just objective difficulty, not examined in the present study, influence effort investment. Factors such as perceived difficulty, known vs. unknown difficulty, incentives, success importance, ability or affect, may account for these discrepancies, as more deeply discussed in 4.5. Our study used unfixed difficulty levels for the participants with unfixed levels of performance to be attained. In this context, it has been shown that effort is more calibrated in relation to success importance (which was not evaluated in our study) rather than difficulty. This may explain why our results did not perfectly conform to the predictions and must be acknowledged.

From our point of view, an important result of the present study concerns the fact that PEP reactivity, whatever the age of participants, was only significant during the very first minute of the realization of a cognitive task lasting more than four minutes. This may appear inconsistent with the necessity to maintain effort to maintain cognitive performance during the entire task. Several hypotheses may be proposed to account for this. One explanation may be that effort is no longer needed after several trials of our tasks, and thus the decrease in PEP reactivity reflects this effort reduction. However, this hypothesis seems unlikely because cognitive task constraints remained the same during the entire task, and behavioral performance remained high. One may also propose that learning effects reduced task difficulty and thus cardiovascular reactivity. However, this hypothesis seems also unlikely because it does not explain why there was a consistent stronger PEP reactivity during the first minute of the second session of the cognitive tasks. Considering that there was no high success incentive and unfixed task difficulty in the present study, one may also hypothesize, based on the motivational

intensity theory (Bhrem & Self, 1989), that participants may have started each task investing high effort and realized that this was not worthwhile, as it was not really rewarded and justified, and reduced effort after one minute. Moreover, given that the cognitive performance is not dependent on solely effort but on other factors, such as ability, persistence or strategy use, a high level of performance could have been maintained even if effort decreased. Finally, it should be possible that subjective perceived difficulty -the most important variable determining effort- can change during task performance, and thus can mitigate the effects of objective difficulty, leading to a decrease in effort investment.

A second set of explanation can also be proposed. One may hypothesize that there is a spontaneous SNS overactivation at the start of the given task to prepare the organism to cope with environmental requirements. This overactivation would cause a temporary decrease in PEP duration at the start of the challenging task, dissipating rather quickly. Obrist and his colleagues have already proposed such an interpretation (Obrist, 1981; Sherwood et al., 1986), that cardiovascular reactivity can be viewed as an anticipatory reflex because, in response to the demands of an aversive cognitive task, for example, "the cardiovascular system may be mobilized in excess of any change in metabolic demands" (Sherwood et al., 1986; p. 102). This supposed overactivation was seen in our present results for each task and each task-repetition, regardless of task difficulty, although it appeared greater when the task was the most difficult. If this hypothesis is correct, PEP reactivity would reflect the temporary activation of the system to cope with a task. Whether this spontaneous SNS overactivation is a reflex or a form of effort, in the sense of Pribram and McGuinness (1975), should be further elucidated. Indeed, these authors stated that effort is involved only when the situation demands the integration and regulation of arousal (to process environmental information) and activation (to generate effective responses) processes to produce a change in information processing competency. Following this definition may explain why effort (and thus PEP reactivity) decreased during task performance in our study, because this need of regulation of arousal and activation decreases as a function of time on task.

It remains to resolve now whether the early PEP decline effect is a psychophysiological process fully explained in the context of the model of effort and cardiovascular response, or a more universal adaptation phenomenon. First, the present study must be replicated with clear examination of the important factors modulating effort intensity, that is task instructions (known vs. unknown difficulty levels; fixed vs. unspecified level of performance), incentive (low vs. high), measure of the perceived difficulty. Second, if the early PEP decline effect is an anticipatory reflex, we should see a constant *overactivation* (strong PEP reactivity) at the beginning of each cognitive task, whatever the number of task repetition or task difficulty. If it reflects effort intensity, we should show a decrease in this *overactivation* as a function of task repetition as well as a task repetition \times task difficulty interaction.

4.5. Limitations of the study

Some limitations of the present study should be outlined. First, we must acknowledge that we manipulated task difficulty by using three tasks that differed by the required level of inhibition control (none; interference control; interference control + response inhibition). This may have created a confound between difficulty and task type. As such, we cannot rule out the possibility that our behavioral and cardiovascular results were not due to the manipulation of task difficulty per se but to different cognitive processes involved in the different tasks. It is difficult to manipulate objective difficulty in inhibition tasks, but employing working memory tasks differing in their cognitive load (such as in N-back tasks for example) may represent a way to overcome this limitation in future studies. Second, as stated above, task difficulty is not the sole factor influencing effort exertion. Important factors, such as perceived difficulty, incentives, success importance, ability or mood, known to have effects on cardiovascular reactivity (see Gendolla, 2025a; Gendolla

et al., 2019; Richter et al., 2016) have not been controlled or manipulated in our study. Also, the fact that the objective difficulty of each task was unspecified to our participants may explain in part some discrepancies in our results and calls for caution in our conclusions. Indeed, under such circumstance, effort should directly

depend on the magnitude of maximally justified effort (i.e., motivation), which was not evaluated here (see Gendolla, 2025a). Finally, the mixed design of our study, with the manipulation of task difficulty within-subject may have some limitations beyond its interest. The processes of habituation and sensitization may be exacerbated in such design, especially given the relatively small sample size of our study (see Hughes et al., 2018). Although promising, the results of this study call for more work to replicate our findings in different contexts taking into account these limitations.

5. Conclusion

The present study reported empirical data that have theoretical and practical implications. PEP and PEP reactivity were somewhat related to cognitive load, but also to time spent on tasks and task repetition. Absolute PEP was higher in middle-aged adults of 55–65 years compared to 20–30-year-olds, but PEP reactivity was not affected by age. Importantly, PEP reactivity showed possible characteristics of habituation and sensitization. Integrating the theory of dual-process habituation (Groves & Thompson, 1970) and the model of effort and cardiovascular response (Wright, 1996) may offer a framework for developing complementary studies to better characterize cardiac reactivity properties and their psychophysiological interpretation. Ultimately, it could be argued that habituation entails a decrease in effort intensity, leading to an increase in PEP duration, whereas sensitization entails an increase in effort intensity, leading to a decrease in PEP duration.

Appendix

Table A1

Mean values (standard deviation) of cardiovascular indices for the young and middle-aged adult groups at the end of the 5-min resting period

	HR (bpm)	SBP (mmHg)	DBP (mmHg)	PEP (ms)
Young adults	81.3 (10)	120 (9)	66 (7.4)	106 (22)
Middle-aged adults	73 (8.6)	120 (12.5)	70.4 (9)	119 (17.6)

HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure; PEP = pre-ejection period

As detailed in the main text (see 2.2), resting values of PEP at the end this initial 5-min resting period were systematically shorter than the ones observed in all the subsequent 3-min resting periods, and also than during all the task periods. This was interpreted as indicating higher cardiac sympathetic activity linked with a probable increased anxiety related to the still unfamiliar laboratory environment and a possible white coat effect. Accordingly, PEP reactivity was computed as the difference between task PEP and resting PEP from the immediate resting period (i.e., the 5-min resting period was not used as a baseline in this study). It is of note that we performed also analyses on PEP reactivity calculated as the difference between task PEP and resting PEP from this initial 5-min resting period. The results of these analyses were largely consistent with the reported results in this manuscript. The only difference concerns the absolute values of PEP reactivity, which were all positive, given that PEP values during this initial resting period were shorter than during the task periods. Moreover, resting PEP values from the initial 5-min resting period significantly correlated with all the resting PEP values from the immediate resting periods (all $r_s(50) \geq .82$; all $p_s < .001$). Finally, PEP reactivity values calculated from the initial 5-min resting period and PEP reactivity values calculated from the immediate resting periods significantly correlated (correlation coefficients ranged from .35 to .56; all $p_s < .01$). Altogether, these results plaid for a coherence of the findings of the present study, even if the absolute PEP values of the initial 5-min resting period were unexpectedly low, comparatively to the other resting periods.

Data Availability

Data will be made available on request.

CRedit authorship contribution statement

Cédric T. Albinet: Writing – original draft, Validation, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Benoît Valéry:** Writing – review & editing, Software, Methodology. **Mickaël Causse:** Writing – review & editing, Methodology, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

Statement: The authors did not use generative AI technologies for preparation of this work.

Funding sources

This work was supported by a grant from the Région Occitanie and the INU Champollion.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationship that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors wish to thank Cindie de Faria for helping in data collection, Jonathan Deniel and Alexandre Obert for helping in statistical analyses, and the professional editor for English editing. The authors wish also to thank the two anonymous reviewers whose comments helped to increase the quality of the manuscript.

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