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## Article

# Cognitive Failures: Relationship with Perceived Emotions, Stress, and Resting Vagally-Mediated Heart Rate Variability

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**Abstract:** Cognitive failures represent everyday task failures that individuals are normally capable of completing. While cognitive failures measured with the Cognitive Failures Questionnaire can be considered a trait, the psychophysiological states associated with cognitive failures are yet to be fully understood. The aim of this paper was to investigate the extent to which the perception of experiencing cognitive failures in daily life is associated with both psychological (i.e., perceived emotional valence, emotional intensity, and stress), as well as physiological (i.e., vagally-mediated heart rate variability, vmHRV) variables. A total of 69 participants were involved in this study (47 male, 22 female; Mage = 22.4 years). Participants underwent a 5-min heart rate variability measurement and filled out the self-report psychological variables, before completing the Cognitive Failures Questionnaire, providing scores for Distractibility, Forgetfulness, and False Triggering. When combining the predictors together into a hierarchical regression analysis, only the model related to the Distractibility subscale was found to be significant (unique significant negative predictor: resting vmHRV). Further research should investigate whether influencing resting vmHRV, with interventions such as slow-paced breathing, may decrease the perception of cognitive failures related to distractibility.

**Keywords:** cognition; executive function; emotion; stress; heart rate variability; cardiac vagal activity; RMSSD



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## 1. Introduction

Forgetting why you went to another room in your house, having to read something again because you did not really pay attention the first time: some people may experience such kinds of cognitive failures every day. While the perception of experiencing cognitive failures in one's daily life can be considered rather stable [1], the psychophysiological states associated with the perception of experiencing cognitive failures are still unknown. Consequently, the aim of this study was to address this gap, focusing on the self-reported affective experience and on the activity of the autonomic nervous system.

Cognitive failures, representing everyday-task failures that individuals are normally capable of completing, can be divided in terms of perception, memory, and motor functions [1–3] and are sometimes referred to as global absentmindedness [4]. Perceived cognitive failures can be measured with the Cognitive Failures Questionnaire (CFQ) [1]. The CFQ comprises three subscales: Distractibility, Forgetfulness, and False Triggering. Distractibility is related to everyday attention, and captures failures associated with faulty

perception and failure to pay attention to relevant stimuli. Forgetfulness relates to everyday memory functioning for actions (e.g., forgetting directions, missing appointments, misplacing items). False Triggering involves slips of action or physical mishaps. Perceived cognitive failures measured by the CFQ are considered as a trait [5] associated with core self-evaluation [6], relatively stable across the lifespan [7], and with a large genetic underpinning [8]. Responses on the CFQ were found to be predicted by some personality traits [9–11], showing mostly negative relationships with conscientiousness and positive relationships with neuroticism.

Regarding psychological variables, some affective states may trigger cognitive failures. In particular, higher perceptions of anxiety and stress, which are typically correlated with less effective cognitive functioning, have also been associated with higher self-reported and observed cognitive failures [11–13]. In the general population, the proneness to perceiving cognitive failures may possibly contribute to the development or persistence of negative symptoms related to psychosis [14]. While causality cannot be inferred from previous research, overall, research points towards a positive association between negative emotional states and perceived stress with the perception of experiencing cognitive failures.

Regarding the physiological states associated with responses on the CFQ, some of the neural correlates of cognitive failures have already been investigated, such as electroencephalography and event-related potentials [15], or in terms of functional connectivity networks with fMRI [16]. However, less is known about the relationship between the CFQ and the autonomic nervous system, in particular with the parasympathetic branch.

Parasympathetic nervous activity can be indexed non-invasively via heart rate variability (HRV), and more specifically via vagally-mediated heart rate variability (vmHRV). HRV represents the time variation between peaks of the QRS complexes [17–19]. HRV represents the key outcome variable of the neurovisceral integration model [20,21], which assumes that there is a core set of neural structures providing the organism with the ability to adaptively regulate cognition and emotions. The neurovisceral integration model is based on the central autonomic network [22], and HRV is considered as the output of the central autonomic network. Further, HRV is suggested to index the degree to which the core integration system guided by the medial prefrontal cortex is integrated with the brainstem nuclei that directly regulate the heart, via the activity of the vagus nerve, the main nerve of the parasympathetic nervous system [23]. Consequently, the focus here is on vmHRV, which represents cardiac vagal activity, the activity of the vagus nerve regulating cardiac functioning.

According to the neurovisceral integration model [20,21], higher cognitive effectiveness is linked to greater activity of the parasympathetic nervous system. This relationship originates from the common structures and networks at stake for cardiac control regulation and for cognitive regulation. Optimal functioning of the prefrontal cortex ensures that the flow of activity along neural pathways will establish adequate mappings and linkings between inputs, internal states, and the outputs needed to perform a given task [24], consequently enabling flexible responses to ever changing environments. To the best of our knowledge, the relationship between vmHRV and the CFQ has never been investigated. When considering perceived cognitive failures, based on the neurovisceral integration model we would predict that a higher vmHRV is associated with a lower perception of experiencing cognitive failures. Specifically, we would expect a stronger relationship with the Distractibility subscale, given distractibility is related to issues with sustained attention, the ability to inhibit irrelevant stimuli and focus on relevant ones, which was found to be predicted by vmHRV [21]. This would also be in line with previous research showing that vmHRV was negatively associated with attentional lapses [25,26]. Attentional lapses, defined as a greater proportion of rare but longer response time, and greater response time variability, can be considered as an indicator of greater distractibility. In this study, we focus on resting vmHRV, specifically when the individual is not engaged in any other activity or task [19,27], and on its association with the perception of cognitive failures happening outside the lab, providing a real-world context to our study.

To sum up, so far little is known about the psychophysiological states associated with the perception of experiencing cognitive failures. Additionally, research examining the relationship between vmHRV and cognitive failures has been mostly lab based, focusing on distractibility and investigating attentional lapses [25,26]. Consequently, the current study aimed to advance the literature by focusing on the perception of cognitive failures that happened outside the lab, in everyday life. Based on the neurovisceral integration model [20,21], we first assume that the subscales of the CFQ, and in particular Distractibility, will be negatively associated with vmHRV. Second, based on previous empirical research, we expect negative affective states to be positively related to all subscales of the CFQ.

## 2. Materials and Methods

### 2.1. Participants

In the absence of previous research related to this topic, we based our power calculation on theoretical considerations, and assumed a medium effect size for the relationship between vmHRV and cognitive failures. A G\*Power (Faul, Erdfelder, Buchner, and Lang, 2009) a priori power calculation for regression analysis (one tail) to detect a medium effect size  $R^2 = 0.25$ , power  $(1-\beta) = 0.80$ , provided an estimated sample size of 59. In order to anticipate for potential dropouts and technical issues, a sample size of 72 participants was recruited to participate in this study. Due to technical issues with the electrocardiography (ECG) measurement of three participants data was removed, and the data of 69 remaining participants were used for the analysis (47 male, 22 female; Mage = 22.4 years, age range = 19–36 years; BMI = 22.74, SD = 1.66). Exclusion criteria were smoking, any kind of self-reported cardiovascular, respiratory, or neurological diseases, any psychiatric disorders, and regular medication potentially affecting the cardiovascular or respiratory systems.

### 2.2. Material and Measures

#### 2.2.1. vmHRV Indexed via Heart Rate Variability

vmHRV was indexed via the root mean square of successive differences (RMSSD), calculated from HRV, given it was found to be relatively free of respiratory influences compared to other vmHRV indicators, such as high-frequency (HF)-HRV [28]. HRV was measured via an ECG device (Faros 180°, Bittium, Kuopio, Finland), at a sampling rate of 500 Hz. We used two disposable ECG pre-gelled electrodes (Ambu L-00-S/25, Ambu GmbH, Bad Nauheim, Germany). The negative electrode was placed on the right infraclavicular fossa (just below the right clavicle) while the positive electrode was placed on the left side of the chest, below the pectoral muscle in the left anterior axillary line. The Kubios software (University of Eastern Finland, Kuopio, Finland) was used to extract RMSSD and the other HRV parameters. The ECG signal was visually inspected for artefacts and corrected manually if needed (<0.01% of the total heartbeats) [19]. Specifically, we used the manual artifact correction mode offered by Kubios, which identifies a R peak on the ECG signal by placing a red cross on it, in case the R peak has not been detected automatically. The RR time courses were detrended using the Smooth priors method, with 500 as a smoothing parameter, and a cutoff frequency of 0.035 Hz. In order to provide an overview of the different HRV parameters, following Laborde, Mosley, and Thayer [19], we also extracted heart rate and the standard deviation of the NN interval (SDNN) for the time-domain and frequency-domain (Fast Fourier Transform), low-frequency (LF: 0.04 to 0.15 Hz), HF (0.15 to 0.40 Hz), and the LF/HF ratio. For the spectral analysis, the following parameters were used: the Fast Fourier Transform spectrum was calculated using the Welch's periodogram method, with a window width of 300s, and a window overlap of 50%. Finally, we also extracted the respiratory frequency from the ECG signal, based on the ECG-derived respiration algorithm of Kubios [29]. The Kubios respiratory rate estimate is computed by using information both from the ECG R-wave amplitude modulation as well as from the power spectral distribution of RR intervals data. This method has been found to be a valid estimate of the respiratory frequency measured directly with either an

impedance-based measurement, a thoracic piezoresistive band, or a spirometer providing continuous ventilatory flow signal [30].

### 2.2.2. Cognitive Failure Questionnaire

We used the German version [31] of the CFQ [1]. The German version of the CFQ contains 32 items with three main dimensions: Distractibility (e.g., “Do you fail to hear people speaking to you when you are doing something else?”), Forgetfulness (e.g., “Do you read something and find you haven’t been thinking about it and must read it again?”), and False Triggering (e.g., “Do you drop things?”). Using a five-point Likert scale (ranging from “0 = never” to “4 = very often”), participants had to indicate how often each of the mentioned events happened to them in the past six months. Reliability in the current study was the following: Forgetfulness ( $\alpha = 0.70$ ), Distractibility ( $\alpha = 0.65$ ), and False Triggering ( $\alpha = 0.66$ ). Alphas between 0.60 and 0.70 are acceptable in smaller samples [32].

### 2.2.3. Visual Analogue Scale—Perceived Stress

A visual analogue scale (VAS), consisting of a 100-mm vertical line, was used to assess perceived stress intensity. The instruction was: “Please indicate on the line below how stressed you feel right now”. The line was anchored by the words “not stressed at all” at the extreme left of the line, and “extremely stressed” at the extreme right of the line. Participants were required to cross a point somewhere on the line, corresponding to their subjective stress intensity. The value of perceived stress intensity was represented by the value (in cm) from the extreme left of the line. Previous research has used this scale to assess perceived stress intensity [33–35].

### 2.2.4. Self-Assessment Manikin—Perceived Emotional Arousal, Perceived Emotional Valence, and Perceived Control

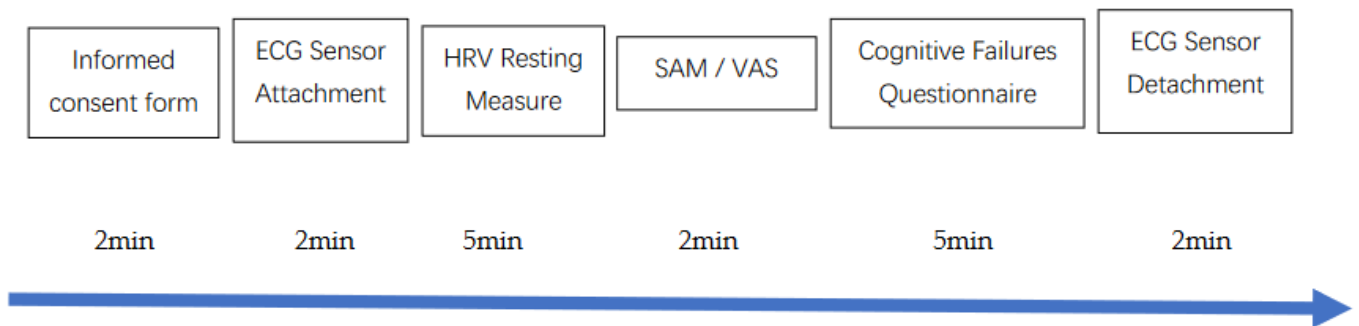
The self-assessment manikin [36] is a picture-oriented instrument containing five images for each of two affective dimensions (i.e., emotional valence and emotional intensity) that the participant rates on a 9-point scale (1 to 9). The main instruction for the two dimensions was: “Please make a cross corresponding to how you feel right now”. Valence is depicted on a negative (a frowning figure), neutral, and positive figure (a smiling figure). The scale was anchored with the words “unpleasant” and “pleasant”. Higher scores reflect a more positive valence. Arousal is depicted ranging from low arousal (eyes closed) to high arousal (eyes wide open). The scale was anchored with the words “calm” and “activated”. Higher scores consequently represent higher arousal.

## 2.3. Procedure

The study protocol was approved by a university research ethics committee (N° 08/2016). Participants were recruited via flyers at a local university campus and via posts on social network groups linked to the university. In line with recommendations for psychophysiological experiments involving HRV measurements [19], participants were instructed to follow their usual sleep routine the night before the experiment, not to consume alcohol or engage in strenuous physical activity in the previous 24 hours, nor to drink any beverage except water or eat 2 hours before taking part in the experiment. All participants gave written informed consent before participating, and were informed that they could withdraw from the study at any time without explanation, and without any consequences. The participants came once to the lab. The whole session lasted 20 min. The full protocol is depicted in Figure 1. After being welcomed to the lab, they were asked to fill out an informed consent form and a demographic questionnaire [19].

Participants were seated on a chair during the entire experiment, with the upper body and the arms being supported. The ECG Faros 180° device for HRV measurement was attached. All measurements were collected with eyes opened, knees at 90°, hands on thighs, and lasted 5 min, following HRV recommendations [17,19]. At the end of the 5-min period, participants completed the self-report measures (SAM and VAS) and the CFQ. At

the end of the experiment, the ECG device was detached, and participants were thanked and debriefed.



**Figure 1.** Experimental protocol. Notes: ECG: Electrocardiography; HRV: Heart Rate Variability; SAM: Self-Assessment Manikin; VAS: Visual Analogue Scale.

#### 2.4. Data Analysis

The HRV data were obtained with the Kubios software. Data were checked for normality and outliers. Regarding outliers, 0.001% of the cases were found to be univariate outliers ( $>2$  SD, z-scores higher than 2.58). Running the analyses with outliers removed did not change the pattern of results, thus we report findings with potential outliers included in analyses. As the RMSSD data were non-normally distributed, a log-transformation was applied, as is often recommended for HRV research [19]. Heart rate [37] and respiratory frequency [19] were also considered as control variables in the analysis (log-transformed). The self-report variables were also mostly non-normally distributed, and similar to RMSSD we applied a log-transformation. Hierarchical regression was used to identify the predictors of each of the CFQ subscales (i.e., Distractibility, Forgetfulness, False Triggering), controlling for age, sex, and BMI at Step 1 [38], and entering the following dependent variables at Step 2: emotional valence, emotional arousal, perceived stress intensity, RMSSD, heart rate, and respiratory frequency. For both steps 1 and 2, variables were entered as a block in a single step with the simultaneous enter method.

### 3. Results

Descriptive statistics can be found in Table 1.

**Table 1.** Descriptive statistics.

	M	SD
VAS—Perceived Stress	7.75	11.80
SAM—Perceived Intensity	1.77	1.09
SAM—Perceived Valence	7.69	1.31
CFQ—Distractibility	1.52	0.44
CFQ—Forgetfulness	0.92	0.48
CFQ—False Triggering	1.19	0.48
Heart Rate (beats per minute)	65.29	9.71
RMSSD (ms)	63.15	34.74
SDNN (ms)	99.16	40.85
pNN50 (%)	29.39	19.17
LF (ms <sup>2</sup> )	4191.88	5196.55
HF (ms <sup>2</sup> )	1426.10	1602.92
LF/HF	4.67	5.51
Respiratory frequency (cycles per minute)	10.24	2.16

Note: VAS: Visual Analogue Scale; SAM: Self-Assessment Manikin; CFQ: Cognitive Failures Questionnaire; SDNN: standard deviation of all RR intervals; RMSSD: root mean square of the successive differences; pNN50: percentage of successive normal sinus RR intervals more than 50 ms; LF: low-frequency; HF: high-frequency.

We performed the multiple regression analyses. For the subscale Distractibility, Step 1 was not significant (adjusted  $R^2 = 0.04$ ,  $p = 0.887$ ); however, the model became significant at Step 2 (adjusted  $R^2 = 0.16$ ,  $p = 0.020$ ). At Step 2, the only significant predictor was RMSSD ( $\beta = -0.397$ ,  $p = 0.025$ ), see Table 2 for detailed results. The models for the other two subscales were not significant: Forgetfulness ( $p = 0.733$ , detailed results in Table 3) and False Triggering ( $p = 0.170$ , detailed results in Table 4).

**Table 2.** Hierarchical regression analysis for the Distractibility subscale.

Model		Unstandardized Coefficient		Standardized Coefficient	<i>t</i>	<i>p</i>	95% Confidence Interval for Beta	
		Regression Coefficient	Standard Error	Beta			Lower Bound	Upper Bound
1	Age	−0.001	0.047	−0.003	−0.024	0.981	−0.041	0.040
	Sex	0.216	0.313	0.101	0.691	0.492	−0.178	0.366
	BMI	0.003	0.088	0.005	0.034	0.973	−0.075	0.078
2	Age	−0.002	0.045	−0.007	−0.055	0.956	−0.040	0.038
	Sex	0.011	0.298	0.005	0.038	0.970	−0.252	0.266
	BMI	−0.087	0.089	−0.146	−0.978	0.332	−0.116	0.040
	VAS—Stress	0.028	0.020	0.326	1.394	0.168	−0.005	0.029
	SAM—Intensity	−0.320	0.218	−0.348	−1.472	0.146	−0.329	0.051
	SAM—Valence	−0.241	0.138	−0.316	−1.750	0.085	−0.224	0.016
	RMSSD	−1.704	0.739	−0.397	−2.305	0.025	−2.314	2.055
	Heart Rate	−0.275	2.500	−0.018	−0.110	0.913	−1.385	−0.095
Respiratory Frequency	−0.034	0.059	−0.074	−0.580	0.564	−1.730	0.978	

Note: VAS: Visual Analogue Scale; SAM: Self-Assessment Manikin; RMSSD: root mean square of the successive differences.

**Table 3.** Hierarchical regression analysis for the Forgetfulness subscale.

Model		Unstandardized Coefficient		Standardized Coefficient	<i>t</i>	<i>p</i>	95% Confidence Interval for Beta	
		Regression Coefficient	Standard Error	Beta			Lower Bound	Upper Bound
1	Age	0.000	0.022	−0.001	−0.005	0.996	−0.045	0.045
	Sex	−0.041	0.150	−0.040	−0.271	0.787	−0.340	0.259
	BMI	−0.012	0.042	−0.043	−0.289	0.774	−0.097	0.072
2	Age	2.245	3.805	0.034	0.251	0.803	−0.042	0.054
	Sex	0.006	0.024	−0.094	−0.603	0.549	−0.412	0.222
	BMI	−0.095	0.158	−0.149	−0.896	0.374	−0.139	0.053
	VAS—Stress	−0.043	0.048	−0.009	−0.033	0.974	−0.021	0.021
	SAM—Intensity	0.000	0.011	−0.144	−0.543	0.589	−0.296	0.169
	SAM—Valence	−0.063	0.116	−0.222	−1.103	0.275	−0.227	0.066
	RMSSD	−0.081	0.073	0.158	0.843	0.402	−1.546	3.800
	Heart Rate	1.127	1.336	−0.096	−0.500	0.619	−0.986	0.592
Respiratory Frequency	−0.197	0.394	−0.227	−1.588	0.118	−2.972	0.342	

Note: VAS: Visual Analogue Scale; SAM: Self-Assessment Manikin; RMSSD: root mean square of the successive differences.

**Table 4.** Hierarchical regression analysis for the False Triggering subscale.

Model		Unstandardized Coefficient		Standardized Coefficient	<i>t</i>	<i>p</i>	95% Confidence Interval for Beta	
		Regression Coefficient	Standard Error	Beta			Lower Bound	Upper Bound
1	Age	−0.018	0.022	−0.101	−0.814	0.419	−0.063	0.026
	Sex	0.180	0.149	0.175	1.208	0.231	−0.117	0.476
	BMI	0.045	0.042	0.157	1.085	0.282	−0.038	0.129
2	Age	−0.010	0.023	−0.056	−0.441	0.661	−0.055	0.035
	Sex	0.139	0.151	0.136	0.925	0.359	−0.162	0.441
	BMI	0.017	0.046	0.061	0.384	0.702	−0.074	0.109
	VAS—Stress	0.010	0.010	0.247	1.005	0.319	−0.010	0.030
	SAM—Intensity	−0.083	0.111	−0.187	−0.746	0.459	−0.304	0.139
	SAM—Valence	−0.079	0.070	−0.217	−1.135	0.261	−0.219	0.060
	RMSSD	1.223	1.272	0.170	0.961	0.340	−1.322	3.768
	Heart Rate	−0.129	0.375	−0.062	−0.343	0.733	−0.880	0.623
	Respiratory Frequency	−1.100	0.788	−0.189	−1.395	0.168	−2.678	0.478

Note: VAS: Visual Analogue Scale; SAM: Self-Assessment Manikin; RMSSD: root mean square of the successive differences.

#### 4. Discussion

The aim of this study was to investigate to which extent cognitive failures experienced in daily life were related to psychophysiological states. Our hypothesis was partially supported. When considering the reciprocal influence of psychophysiological states within a hierarchical regression model, the model predicting the Distractibility subscale was found to be significant, with resting vmHRV a significant predictor, while the self-report psychological variables emotional valence, emotional arousal, and perceived stress intensity did not contribute significantly to the model. The models for Forgetfulness and False Triggering were found to be non-significant.

Our findings of vmHRV negatively predicting perceived distractibility are in line with the neurovisceral integration model [20–22]. Specifically, this model suggests that vmHRV, being an outcome of the central autonomic network [22], represents the effectiveness of executive functioning. This stems from vmHRV reflecting the ability of the organism to adequately adjust sufficient mappings between input, internal states, and outputs needed to perform a given task [24]. This theoretical rationale provides a basis for higher resting vmHRV being a protective factor against distraction, and hence related to lower perceived distractibility. In lab research, vmHRV was shown to be a marker of selective attention and to be a protective factor against distractors [39–41]. VmHRV was also negatively related to attentional lapses [25,26], as measured with intraindividual response time variability. The current research extends lab-based findings linking vmHRV to perceived distractibility in a real-life context. The finding that vmHRV was associated with Distractibility but not to the other subscales may point toward the fact that the neurophysiological mechanisms underlying cognitive failures differ based on the nature of cognitive failures. Further research is therefore encouraged to investigate the perception of cognitive failures using physiological measurements other than vmHRV, such as with electroencephalography [42,43].

Contrary to our hypothesis, the subjective psychological variables did not predict the CFQ subscales. The finding that, when associated with physiological variables in the hierarchical regression analysis, and in particular to vmHRV, the psychological variables do not contribute significantly to the subscale Distractibility, may be related to the state/trait nature of the variables. Given the CFQ is supposed to reflect stable dispositions of the individual, thus the stronger association with vmHRV in comparison to state psychological variables may be due to the trait nature of vmHRV [44]. After considering potential influential factors [45,46], vmHRV was deemed to be relatively stable [44]. On a methodological level, it would be interesting to test the relationship between psychological affective states and cognitive failures in real time, either observed during experiments or self-reported.



Our study had some strengths, such as being the first novel empirical test of the relationship between cognitive failures and vmHRV. Nonetheless, our study also had some limitations. First, other variables that may influence cognitive failures, such as personality traits [9,10], have not been controlled for. Second, our sample was unbalanced regarding sex, with 22 female and 47 male participants. Despite of the fact sex was controlled for in the statistical analyses, further studies should endeavor to recruit more balanced samples in terms of sex, given sex is known to influence HRV [38]. Third, self-report retrospective measures of cognitive failures may be biased, and future research should consider including objective measures of cognitive failures and cognitive performance. Fourth, our sample of young adults may not experience many cognitive failure symptoms, and future research should consider investigating the relationship between vmHRV and perceived cognitive failures in older adults. Fifth, we likely overestimated the strength of relationship between vmHRV and perceived cognitive failure in our a priori power calculation. Computing the achieved power of our study with G\*Power returns a value of power  $(1 - \beta) = 0.62$ . Future research should consequently test a larger sample size when investigating the links between vmHRV and perceived cognitive failures. Finally, we only considered here the relationship between the CFQ and resting vmHRV. In line with recent theoretical and methodological recommendations and the “3 Rs” (i.e., resting, reactivity, recovery) of vmHRV functioning advocated by the vagal tank theory [19,27], future research should investigate the relationship of the CFQ together with vmHRV measured during (i.e., reactivity) and after (i.e., recovery) for example cognitive or emotional tasks.

## 5. Conclusions

The potential negative consequences of cognitive failures, which go from potentially rather harmless daily small distractions to more serious consequences with accidents [47–49], triggered the interest of researchers to develop interventions to face cognitive failures. Those interventions considered different time scales, and were realized either on an acute basis manipulating the perceptual load [50], or on a more chronic basic, with long-term interventions based on mindfulness [51] or targeting stress management [52].

Taking into account the findings of the current study that resting vmHRV was negatively associated with the perception of experiencing cognitive failures (Distractibility) in daily life may pave the road for the development of a new line of interventions to help people cope with cognitive failures. Specifically, interventions aiming to increase vmHRV [46,53], such as those based on slow-paced breathing, may provide both support for a quick fix [54,55] or a long-term benefit [56]. Specifically, slow-paced breathing has been shown to improve executive functioning [57,58] and in particular inhibition, which would play an important role into decreasing the tendency to distractibility. Consequently, future research should aim to further understand the psychophysiological correlates of cognitive failures, in order to help high scorers better face everyday challenges with less cognitive failures.

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