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A psychophysiological investigation of the interplay between orienting and executive control during stimulus conflict: A heart rate variability study

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ABSTRACT

Background: It has been hypothesized that resting state cardiac vagal activity (CVA) - an indicator of parasympathetic nervous system activity - is a specific psychophysiological marker of executive control function. Here, we propose an alternative hypothesis - that CVA is associated with early stage attention orientation, promoting the flexible uptake of new information, on which the later operation of such executive control functions depends. We therefore predicted that CVA would predict the interaction between orienting and executive control. This was tested using the revised version of the Attention Network Test (ANT-R) that was developed to distinguish between orienting and executive attention during a stimulus conflict task.
Methods: Healthy adults ($N = 48$) performed the ANT-R and their resting CVA was measured over a 5 min period using ECG recordings.
Results: Multiple regression analyses indicated that, when other factors were controlled for, CVA was more strongly associated with the interaction between the orienting and executive control terms than with either factor individually.
Conclusion: Higher levels of CVA are specifically implicated in the modulation of executive control by intrinsic orientation operating at early stages of conflict detection. These initial findings of higher CVA on orienting attention in conflict detection need to be replicated in larger samples.

1. Introduction

Even in the simplest and most repetitive of everyday cognitive tasks, where the same response to the same stimulus is required over and over again, the schedule of forthcoming events is not completely predictable. Every so often a stimulus may indicate that a different, conflicting, response (i.e., a different button press) is required from that established as part of the dominant response set. The attentional flexibility that promotes the resolution of such stimulus conflict and enables an alternative action pattern to be adopted and the correct response to be made, therefore, represents a core element of effective information processing in situations of cognitive conflict [33]. The *Attentional Network Theory* [36,40] takes a system neuroscience approach to explaining this phenomenon. It posits that flexibility of responses to changing external context depends, in part, on the brain systems that mediate an individual's initial pattern of orienting to new and changing salient stimuli - both intrinsic, and extrinsic. These early operating systems modulate the activity of later higher order executive control

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processes [15,16,19]. In goal-oriented behavior, intrinsic, top-down attention allocation at early stages of conflict monitoring is crucial for allowing a flexible response during the conflict detection process [36,40]. This occurs through rapid prioritization and allocation of resources during the initial engagement with, and processing of, external spatial stimuli cueing the location of future response conflict episodes [15,31,36,39,40,57]. This allows one's attention to engage with salient external warning cues, at the same time as refocusing on task-relevant stimuli– a necessary feature of effective conflict detection.

The regulation of stimulus conflict varies as a function of individual differences in physiological characteristics. For instance, theorists have proposed that individual variation in resting state vagally-mediated heart rate variability (or cardiac vagal activity (CVA) - a core marker of parasympathetic nervous system (PNS) activity), is related to cognitive flexibility and because of this indexes an individual's ability to engage in executive inhibitory processes to resolve stimulus conflicts during tasks. In these models, and in two recent meta-analyses [23,60], higher resting CVA is associated with higher levels of task-related executive control ([37,52–54]. This model is based on the idea that both cardiac function, via the PNS, and executive functions, are regulated by prefrontal cortex activity [23,37,53,54]. PNS activity slows heart rate; the sympathetic nervous system (SNS), in contrast, provides excitatory stimulation to up-regulate heart rate and increase associated arousal [37,53,54]. PNS and SNS interplay controls beat-to-beat heart rate, while PNS innervation increases variability through a short heart rate response latency and a quick return to baseline level [37,53].

However, it is important to broaden the scope of enquiry in examining the association between PNS and other cognitive stages and processes. For instance, the existing literature shows a consistent, but small, association between PNS activity and executive control [23,60]. Furthermore, at a behavioral level it is known that orienting and executive systems interact to control conflict monitoring; this may also be the case at the psychophysiological level [15,31]. Reduced tonic alertness is associated with both poorer initial orienting and later executive control [7,17,34]. Presentation of a valid orienting cue (assessing exogenous orientation) enhances the ability to handle conflicting responses, whereas invalid orienting cues weaken this ability [15]. Furthermore, based on neuroimaging studies such interactions are located within the dorsal attention system, the neural hub of the endogenous orienting attention (i.e., intraperietal sulcus and frontal eye fields: see [11,36]), and interact with the executive control network during an attention selection task [14]. Increased activity within the salience network (implicating the anterior cingulate cortex, anterior insula and thalamus) leads to improved target detection by regulating the level of tonic alertness [12].

In the current paper we explore the interaction between the executive and orienting systems and its relationship to CVA using the *revised Attention Network Test* (ANT-R; [15]). We will test the hypothesis that CVA is related to the interaction term indexing the modulation of executive control by prior orienting processes. We predict that CVA will predict the term representing the size of the orienting-executive control interaction more strongly than the main effects of orienting or executive control. Specifically, we predicted that higher resting CVA would better predict endogenous orienting in situations requiring executive control (i.e., following the presentation of invalid cues), leading to more efficient conflict detection.

Two studies using modified versions of the Eriksen flanker paradigm have shown that a higher CVA is associated with faster reactions and lower variability of reaction time parameters [2,59]; however, these studies observed no specific relationship with executive control reaction time scores. Also, one study, using the original ANT, has previously demonstrated that higher CVA predicts better endogenous orienting independent of executive control [42]. However, this study characterized orienting in terms of a single network score. This meant that it was not possible for the authors to investigate the interaction between orienting and executive control as required to test the current hypothesis. Also, the original ANT is limited in its characterization of orienting because it does not allow for a comparison of responses to valid and invalid cue conditions [15]. The ANT-R was designed to disentangle orienting and executive control from a third system, alerting [36,40] and to enable researchers to study the interactions between intrinsic attention allocation (i.e., orienting) and executive control [15]. This is made possible by the inclusion of a flanker condition in which temporal and spatial cues are presented before the flanker stimuli. In contrast to the original version of the task, the flanker stimuli appear at two different spatial locations, either on the right or left hand side of the computer screen - resulting in a measure of a spatial cuing, indicating the valid or invalid spatial appearance of the flanker stimuli - in accordance with Posner's [38] original approach to measuring the orienting network. Therefore, in the current experiment, orienting was indexed by response times to invalid spatial cues minus those to valid spatial cues presented during conflict monitoring to assess the ability to disengage from task-irrelevant stimuli [9,15]. Executive control was indexed by reaction times to incongruent flanker stimuli (conflict between the center arrow and the flanker arrows) minus responses to congruent flanker stimuli (no conflict between the center arrow and the flanker arrows).

In summary, there is a lack of studies on the relationship between CVA and the role of attention allocation in executive control processing as represented by the orienting x executive interaction score. Prior studies (see [23,60]) have predominantly used neuropsychological tasks that do not distinguish between different aspects of attentional control as distinguished in the Attentional Network Theory [36,40]. We therefore aimed to test the relationship between CVA and the interaction between early attention allocation through endogenous orienting and later stage executive control – which we hypothesized is important for flexible responding and efficient conflict detection. This interaction represents efficient early disengagement from irrelevant, salient stimuli

Table 1
Descriptive information about the ANT-R scores.

Attention networks	Variable score:	Measures:	Operational score calculation:	M (SD)
Alerting	Alerting	Tonic[a] and phasic arousal (temporal cues)	RT_no cue - RT_double cue	42.96 (30.58)
Orienting	Validity effect	Endogenous[a] and exogenous att. engagement (spatial cues)	RT_invalid cue - RT_valid cue	105.19 (37.43)
Executive control	Flanker conflict	Conflict processing (congruent and incongruent conditions)	RT_fl. incongr. - RT_fl. congr.	151.91 (44.85)
Interaction scores				
Alerting-executive	Alerting*flanker	The effect of alerting (temporal) cues on the conflict processing[a]	(RT_no cue, fl. incongr. - RT_no cue, fl. congr.) - (RT_double cue, fl. incongr. - RT_double cue, fl. congr.)	20.81 (52.26)
Orienting-executive	Validity*flanker	The effect of orienting (spatial) cues on the conflict processing[a]	(RT_invalid cue, fl. incongr. - RT_invalid cue, fl. congr.) - (RT_valid cue, fl. incongr. - RT_valid cue, fl. congr.)	70.12 (48.12)

Note. RT = reaction time; fl. = flanker; incongr. = incongruent; congr. = congruent; att. = attention.

[a] Lower scores indicate the intrinsic, self-regulated effect on alertness and orienting.

in the pursuance of goal-oriented executive behavior (i.e., conflict detection) (see Table 1). More specifically it represents the effect of endogenous orienting on performance in the incongruent flanker condition (i.e. during stimuli conflict, when executive control is required). Our expectation was therefore that higher CVA will predict individual differences in how the presentation of invalid cues disrupts flanker-related conflict monitoring in the incongruent condition associated with more efficient re-engagement of attention leading to more efficient conflict detection.

2. Materials and methods

2.1. Participants

Participants were recruited from the student population of the *University of Bergen* through internal announcements by email and on a university webpage. The study was part of a larger study investigating aspects of mindfulness and its association with attention networks and psychophysiological measures considered to be included in a larger planned randomized controlled study (see also [46–48,56]). Exclusion criteria were: severe psychiatric illness; cardiac illness, use of sedative or psychoactive medication and previous experience with mindfulness, i.e. attended mindfulness courses, participation in mindfulness retreats or received other kinds of formalized mindfulness training. Fifty-three participants were recruited, and 50 of them performed the ANT-R. Results from two participants were excluded because of poor physiological data quality. Subsequently, 48 participants were included in the current study. They were 19–29 years of age (mean age = 23.44; SD = 2.22; 73% females) and with a mean body mass index (BMI: weight/height^2) of 22.05 (SD = 3.60). All participants provided informed consent in accordance with the Helsinki declaration and the approval of the study protocol by the Regional Ethics Committee (South East: Study number 2014/148).

2.2. Procedures

Data were collected at approximately the same time in the afternoon for all participants in order to control for circadian effects [5]. Participants were asked to refrain from intake of nicotine and caffeine three hours prior to the experiment. Furthermore participants were required to refrain from alcohol or psychoactive drugs the day of the experiment. Participants performed the ANT-R at the same session as the heart rate recording. The order was counter-balanced, either starting with the ANT-R or with the recording of the electrocardiogram (ECG).

2.3. The revised attention network test (ANT-R)

The ANT-R [15,31] is based on the original attention network test [16], using a flanker condition that varies according to cue conditions. The flanker condition generates a measure of the executive control network, whereas the cue conditions generate measures of the attention networks of alerting and orienting. The revised version uses three cue conditions (no cue, double cue, spatial cue) and two target conditions (congruent and incongruent). Participants were presented with a target stimulus, a center arrow flanked by two arrows on each side (flanker condition; see Fig. 1 and Table 1). They were instructed to indicate the direction of the center arrow by pressing a key with the index finger for the left direction and with the ring finger for the right direction on a mouse. A congruent flanker condition was presented when the center arrow pointed in the same direction as the flanker arrows. An incongruent (conflict) flanker condition was presented when the center arrow pointed in the opposite direction from the flanker arrows. A fixation cross was presented in all trials. This was followed by the appearance of the row of arrows on either the left hand side or on the right hand side of the screen for 500 ms. Different cue conditions were presented for 100 ms before the target arrows appeared, illustrated by flashing boxes. These cues could indicate the spatial presentation of the flanker condition (valid cue) or not (invalid cue), or alternatively, temporal cues could be presented by both the boxes on the right hand and left hand sides flashing (double cue), or no boxes were flashing before the presentation of the flanker condition (no cue). The cue presentation was programmed such that each type of cue was preceded by every other type of cue at an equal frequency. Embedded within each cue condition were twenty-four combinations of the cue-to-target intervals (0, 400, and 800 ms) by two flanker conditions (congruent, incongruent) by two target locations (left, right). The presentation order was randomized. Participants performed a practice task with step-by-step instructions for the cue and target conditions, in which they responded on six practice trials with a limitless response time window, and thereafter on 32 practice trials with the same timing limits as the real ANT-R. In the current study, participants performed the ANT-R with ≥80% accuracy. The generated scores for orienting and executive control were used to calculate the orienting-executive control interaction score (comprising the operation of calculating three difference scores; see Table 1 and *Supplemental Material* the calculation of the ANT-R scores).

The ANT-R comprises 4 runs with 72 test trials in each run. The cue conditions are counterbalanced across two runs consisting of 144 trials (see [15] for more details). The task was run on a desktop PC, using *E-Prime*™ software (Psychology Software Tools, Pittsburgh, PA).

2.4. Electrocardiogram (ECG)

Heart rate was measured using an analog ECG signal recording in a simple lead II configuration. The signal was obtained through an A/D converter (Biopac MP36, Biopac system INC. Santa Barbara, CA) and sampled at 1 kHz. Participants were asked to sit in a comfortable position and to relax during the ECG recording. The first five minutes of each recording were subjected to further analysis, see below.

2.4.1. Heart rate variability analysis

R-peaks in the ECG signal from the resting condition were identified through the algorithm implemented in Kubios version 2.0 software [49]. The identified R-spikes in the ECG signal were later subjected to visual inspection, so that in a few cases, erroneously identified R-peaks by the automated procedure of QRS detection were moved manually to the position of the true R-peaks in the ECG (see [49]). After automatic and visual inspection of the ECG data, no artifacts were detected. To increase the signal-to-noise ratio of the ECG data, non-stationary trends were removed with the smoothness priors detrending method as incorporated in Kubios [50]. Two separate measures of CVA were derived: The root mean square of successive differences (RMSSD) of R-R intervals, and spectral analysis using a Fast Fourier Transformation (FFT). In the FFT analysis spectral components of the high frequency, in the 0.14–0.4 Hz frequency band, were quanitifed in absolute units (HFms^2). The heart rate variability measures were log transformed in order to approximate a normal distribution [13,29]. In the current study, we included the RMSSD as the measure of heart rate variability, which is considered a valid measure of CVA [3,30,44,55,58]. RMSSD correlated highly with HF power ($r = 0.94$, $p < .001$). A recent meta-analysis [23,60] showed that the time domain (RMSSD) and frequency domain (HF) of CVA appeared to yield similar results in relation to executive control. However, RMSSD has been shown to be less affected by respiration frequency than HF [22,35]. We included HF-peak as a measure of respiration rate in the statistical analyses (see [41,58]). The HF band measure was included only to investigate whether the frequency domain measure CVA would yield the same results as RMSSD for the resting CVA in the *Supplemental Material* ([29]; Task Force [51]).

2.5. Statistical analyses

All statistical analyses were performed in SPSS, Version 24.

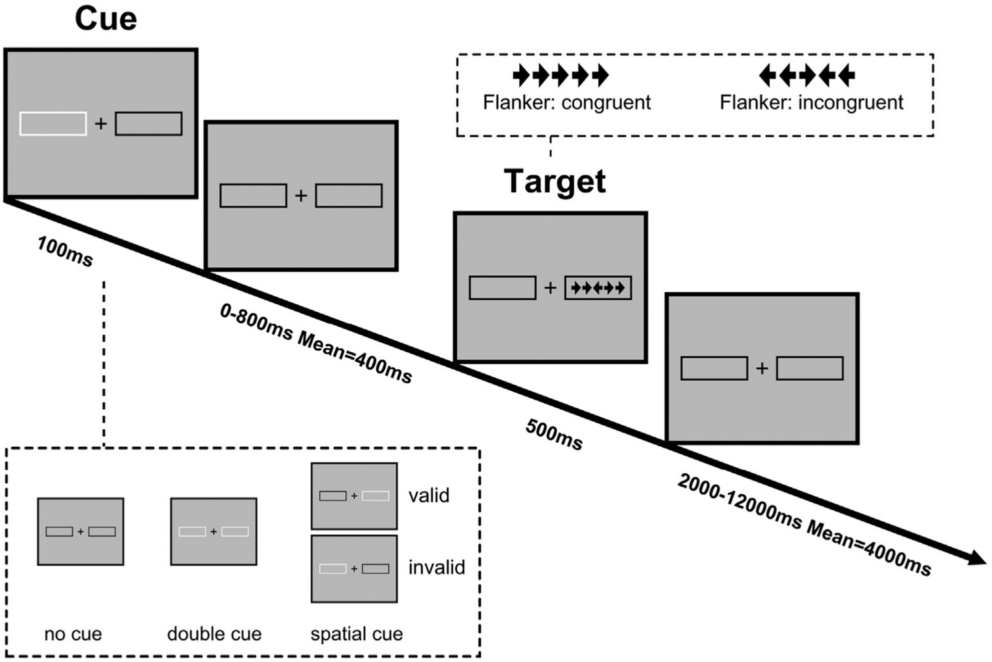

Fig. 1. Schematic of the ANT-R.
After the fixation cross is shown a cue condition is presented (none, double, and valid or invalid ones) with a cue box flashing for 100 ms. Thereafter with variable period (0, 400, or 800 ms), the row of arrows are presented for 500 ms with one target arrow (center arrow) and two flanker arrows on each side of the target arrow (congruent or incongruent). Participants are instructed to respond to the direction of the target arrows.
(modified from [15]).

Preliminary analyses of bivariate correlations were conducted to investigate if age [43] was associated with CVA and ANT-R scores or BMI [26] with CVA. Independent *t*-tests were conducted to investigate the effect of sex on CVA [27] and ANT-R scores. The effect of age, sex, and BMI would only be controlled for in the statistical analyses if they were shown to be associated with CVA and/or ANT-R scores. Also, the effect of mean heart rate, HF peak, and the counter-balanced order of assessment of CVA before or after the ANT-R were investigated in relation to CVA, age, sex, and BMI with analyses of bivariate correlations, independent *t*-tests, or chi-square tests, respectively. No outliers were detected in any measure of interest (± 3 standard deviations from the sample mean).

We conducted Pearson bivariate correlational analyses and multiple linear regression analyses to test whether CVA was associated with the ANT-R scores for alerting, orienting, executive control and the orienting-executive control interaction. In the linear regression analyses, CVA was included as the predictor and ANT-R scores as dependent variables, respectively. Analyses were adjusted for confounding variables based on the preliminary analyses, and further, adjusted for multiple testing by using Bonferroni correction of the alpha level ($p = .05/5 = 0.01$). In follow-up linear regression analyses, we included the counter-balanced order of assessment of CVA before or after the ANT-R as a covariate, and examined if this counter-balanced order had an influence on the findings. We also investigated the effect of mean heart rate on the ANT-R scores in subsequent analyses to test the specificity of the effect of CVA on attention abilities. As Supplementary Material, two separate regression analyses were conducted with each of the ANT-R scores as outcome variables, respectively, based on whether CVA was measured before or after performing the ANT-R. We also tested the specificity of the relationship between CVA and the orienting-executive control interaction score by conducting an additional linear regression analysis with CVA as the outcome variable and the all ANT-R scores (alerting, orienting, executive control, alerting-executive control, and orienting-executive control) as predictors.

3. Results

3.1. Preliminary analyses

Orienting, but not executive control, correlated positively with the orienting-executive control interaction term. There was no correlation between CVA and BMI or age. There was a significant effect of sex on CVA level ($t = -2.60$, $p = .01$), with higher CVA in females than in males. There was no effect of sex or age on any ANT-R scores – both in bivariate and multivariate analyses. Mean heart rate only correlated negatively with CVA (Table 2), and not with age nor BMI. Sex differences on mean heart rate did not reach statistical signficance ($t(46) = -1.84$, $p = .07$). The variable representing the counter-balanced order of CVA and ANT-R assessment order influenced CVA ($t(46) = -2.03$, $p = .048$) and mean heart rate ($t(46) = 3.33$, $p = .002$). The distribution of age, BMI, and sex were not different between the two counter-balanced assessment groups. HF-peak did no correlate with

Table 2
The bivariate correlations between level of resting CVA and the ANT-R scores.

N = 48		2.	3.	4.	5.	6.	7.	8.
1.	Resting-CVA	−0.39**	0.23	−0.10	−0.30*	0.06	−0.06	−0.52**
2.	Mean heart rate		−0.08	0.07	0.02	−0.12	0.14	0.08
3.	HF-peak			−0.14	0.04	0.09	−0.01	0.22
4.	Alerting network				0.05	0.16	0.28	−0.14
5.	Orienting network					−0.25	0.01	0.63**
6.	Executive control network						−0.06	−0.10
7.	Alerting-executive							0.09
8.	Orienting-executive							

** $p < .01$.
* $p < .05$.

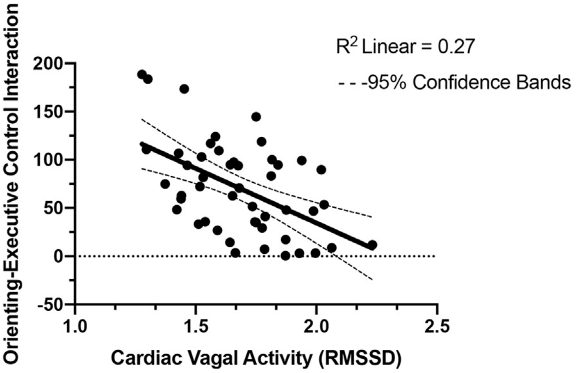

Fig. 2. The relationship between level of resting cardiac vagal activity and the ANT-R orienting-executive control interaction term.

level of CVA, age, or BMI, nor did sex effect level of HF-peak.

3.2. The association between the CVA and the ANT-R scores

Higher CVA was correlated with both lower orienting scores and lower orienting-executive control interaction scores (Table 2 and Fig. 2; see also Supplemental Table 1). However, when controlling for the confounding effect of sex and multiple testing using multiple linear regression models including the ANT-R scores and sex as predictors, higher CVA only predicted lower orienting-executive control interaction scores and no other ANT-R indices (Table 3). This significant relationship between higher CVA and a lower orienting-executive control score did not change when further adjusting for the counterbalanced order of assessment of CVA pre- or post ANT-R as a covariate ($R^2 = 0.27$, $F(3,44) = 5.52$, $p = .003$; CVA: $\beta = -0.54$, $t = -0.3.74$, $p = .001$; see also Supplemental Table 2). Also, neither mean heart rate nor HF peak correlated with the ANT-R scores (Table 2). Furthermore, it was further only the orienting-executive control interaction score that associated with higher CVA when including all the ANT-R scores (alerting, orienting, executive control, alerting-executive control, and orienting-executive control) as predictors in the same linear regression analysis (see Supplemental Table 3).

4. Discussion

Our results are consistent with the hypothesis that CVA is associated with the interaction between early endogenous orienting and later executive control indexed as by successful detection of incongruent flankers. This beneficial effect of CVA on orienting attention represents a faster selection of relevant stimuli to enable more efficient monitoring and detection of flanker conflicts. Thus, the orienting-executive control interaction term measures the specific effect of endogenous orienting on the incongruent flanker condition (i.e., stimuli conflict) when executive control is required. Higher CVA appears thereby to specifically enhance voluntary, early operating orienting attention, and not conflict detection per se.

To our knowledge, this is the first study to show such a relationship between higher CVA and better early attention allocation abilities when modulated by executive control. We used the revised ANT to study the interaction between attention networks. This allowed us to subdivide task processing into two subcomponents: intrinsically regulated attention allocation processes (i.e. endogenous orientation), and executive control (i.e., flanker conflict detection). Traditionally, following the theory of Thayer and colleagues, previous studies on CVA and executive functions have typically applied more general, non-specific measures that do not allow the specific role of orienting to be distinguished [23]. Our results thus show that executive processes benefit from higher CVA. However, this beneficial effect seems to be facilitated by enhanced attention allocation during endogenous orienting attention. Such enhanced orienting would be of value when new information appears that could be relevant during the early stages of conflict detection. In this way higher CVA may promote the flexible uptake of new, relevant information (valid cues) during goal-oriented behavior at the same time as ensuring the maintanence of attentional focus on task-specific stimuli in the face of irrelevant, potentially distracting cues. Reinforcing the importance of studying executive and orienting processes jointly, our results indicated greater effect sizes for an association between CVA and the orienting-executive control interaction than those previously observed in studies using more non-specific measures of executive function [23].

Findings from the current study align with Porges' [37] model, suggesting that higher CVA allows “the individual to rapidly engage and disengage with objects and other individuals” (p. 9). Further, it is also consistent with the results of a previous study [42] that found CVA to be uniquely associated with better endogenous orienting attention using the original ANT. However, this particular study could not investigate the interaction between orienting and executive control.

Our own study illustrates that endogenous orienting does not facilitate both incongruent and congruent conflict detection. Rather, CVA appears to enhance levels of endogenous orienting attention specifically in interaction with executive control processing, as measured during incongruent conflict detection. Top-down regulation of endogenous orientation allows us to re-direct our attention to pursue goal-oriented behaviour when presented with competing irrelevant salient events [11] (see Fig. 3).

Recently the need to study the interaction between control subcomponents has been highlighted [4], emphasizing the importance of supportive processes, such as attention allocation, on the implementation of conflict detection [10,25]. This has, as far as we know, not been studied previously in relation to individual differences in CVA. The majority of the studies included in the two meta-analyses of the relationship between CVA and executive control used classical neuropsychological tasks that did not distinguish attention allocation from executive control in goal-oriented behavior [23,60], such as the Stroop interference task (i.e., [8,24]), working memory tasks (i.e., [20,21]), or

Table 3
The prediction of level of resting CVA on the ANT-R outcome scores.

Model	Outcome score	Predictors	R^2	F	p (F)	β	t	p (t)
1	Alerting network	Sex	0.02	0.38	0.69	0.09	0.59	0.56
		Resting-CVA				−0.06	−0.39	0.70
2	Orienting network	Sex	0.11	2.89	< 0.07	−0.17	−1.10	0.28
		Resting-CVA				−0.36	−2.38	0.02
3	Executive control network	Sex	0.00	0.08	0.93	0.04	0.03	0.98
		Resting-CVA				0.06	0.38	0.71
4	Alerting-executive	Sex	0.02	0.51	0.60	−0.15	−0.93	0.36
		Resting-CVA				−0.11	−0.71	0.48
5	Orienting-executive	Sex	0.27	8.38	< 0.01**	< 0.01	−0.01	0.99
		Resting-CVA				−0.52	−3.83	< 0.01

Note. $N = 48$. **Bonferroni correction of alpha level: p = .05/5 = 0.01; df of F = 1,44.

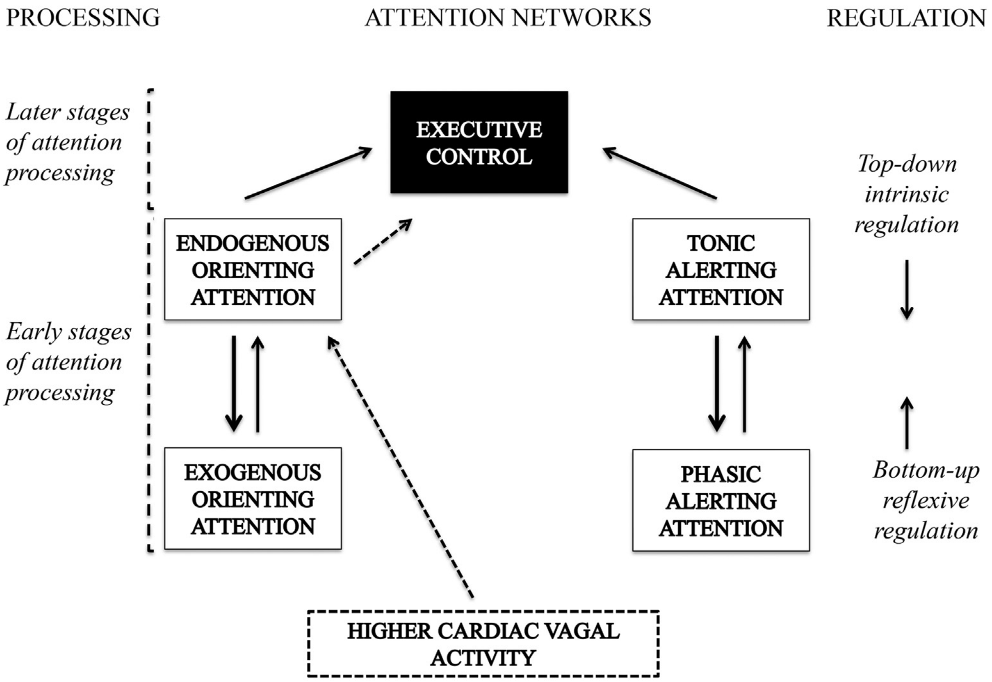

Fig. 3. A model depicting the relationship between higher cardiac vagal activity and the three networks of attentional control. The findings from the current study indicate that higher levels of cardiac vagal activity index an enhanced endogenous orienting attention in filtering the surroundings for relevant stimuli to pursue goal-oriented behavior. And that the ability to disengage attention from irrelevant stimuli makes the flanker incongruent conflict detection (executive control) more efficient. However, we found that a higher cardiac vagal activity does not predict specifically better executive control, higher phasic or tonic alertness, or the stimulus-driven exogenous orienting attention.

the Wisconsin card sorting task (i.e., [1,24]). In fact, the small effect sizes found in the two meta-analyses [23,60] do not provide convincing evidence that higher CVA specifically predicted more effective and/or efficient executive control. The limited studies that have adopted experimental paradigms allowing for testing a more specific measure of executive control with either ANT or flanker paradigms have all showed no association between higher CVA and detecting conflicts in the incongruent conflict condition compared to the congruent [2,42,59]. At the same time, the small effect sizes found in the meta-analyses [23,60] may indicate a need of a larger sample than is included in the current study to detect a significant association between CVA and executive control. Thus, Willams and colleagues [59] included a sample of 104 healthy adults but did not find even a statistical tendency for a relationship between CVA and the flanker paradigm-generated executive control score.

The *Attention Network Theory* predicts that increased alertness (a third element in the theory) is also important, both for attention orientation and executive control [7,17,18,39]. It allows shifting between rest and active performance states [15,39], which is thought to be dependent on the regulation of the ANS and the balance between sympathetic and parasympathetic activation [37]. In light of this information, one might predict that higher CVA would also relate to superior alerting scores on the ANT-R. However, we did not predict such an association because a previous study using the original ANT observed no relationship between CVA and the alerting network score [42].

Theoretically it has been suggested that measuring CVA at resting state without prior experimental cognitive requirements assesses a different physiological state than measuring it after performing a cognitive task [28,29]. Since our study design incorporated assessing CVA either before or after performing the ANT-R (as the order was counterbalanced), we tested if the design (i.e., time of CVA assessment) resulted in differential effects of CVA on the ANT-R indices. Our results showed that this did not differentially affect our finding of higher CVA predicting a more efficient orienting-executive control interaction specifically. This is in line with the recent meta-analysis showing resting CVA and phasic CVA to relate similarly to cognitive measures [23].

The ability to intrinsically govern the allocation and orientation of attentional resources in accordance with contextual demands may be relevant for understanding the role that psychophysiological flexibility, as indexed by CVA, plays in emotion regulation (see [3]). Early processing stages of emotion regulation strategies are viewed as more adventogous compared to later processing stages, since the intensity of emotions tends to become higher in the later stages and thereby more challenging to modulate [45]. In the early processing stages, redirecting attention to other neutral aspects of the surrounding environment is shown to be a good strategy to assist in down-regulating emotion of high intensity. As such, superior abilities of endogenous orientation following higher CVA may facilitate better access to emotion regulation strategies. Our findings highlight the importance of early attention allocation during orientating, that may also be relevant for studies of the effects of mindfulness training on attention abilities. This type of training is thought to enhance the early attention allocation in conflict detection [32,47]. The ANT-R thus offers the possibility to study how early stages of attention allocation interact with the executive control processing in later stages of goal-oriented behavior. This offers a unique opportunity for future studies to gain a better understanding of the interaction between CVA, attention allocation, and executive control in mental health disorders and as measures of treatment effect. Also of interest for future studies is the role of the SNS on attention processing and conflict detection, which, for instance, may provide a better understanding of the psychophysiological processes of the alerting attention network. CVA can be measured during the performance on the ANT-R in combination with measures of SNS, such as skin conductance and/or cardiac pre-ejection period (see [6]).

5. Conclusion

A recent meta-analysis [23] suggested that higher levels of CVA mark better general self-regulative abilities. The current study, however, points to higher CVA as a specific marker of flexibility in self-regulative abilities. Early adjustments of attention allocation through orientation to situational contexts can thus be benefical for goal-oriented behavior. This is consistent with theories of CVA [37,53,54], emphasizing that CVA is a psychophysiological index of adaptive responses to changing situational demands. Due to the relatively small sample size in the current study, these initial findings need to be replicated by studies with larger samples.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.physbeh.2019.112657.

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