Mindfulness
https://doi.org/10.1007/s12671-022-01850-6

ORIGINAL PAPER

Individual Differences in Dispositional Mindfulness Predict Attentional Networks and Vigilance Performance

Luis Cásedas[1,2] · **Ausiàs Cebolla**[3] · **Juan Lupiáñez**[1,2]

Accepted: 22 February 2022

Abstract

Objectives Research addressing the relationship between dispositional mindfulness and objective attention performance remains inconclusive, partly because previous studies used sample sizes possibly leading to underpowered designs. Here, we examined this relationship in a large sample using the ANTI-Vea: a novel cognitive-behavioral task that simultaneously assesses the classic attentional networks—phasic alertness, orienting, executive control—and both the executive and arousal components of vigilance.

Methods Two hundred nineteen meditation-naïve participants completed the study. Correlational analyses using Kendall's Tau were performed between FFMQ scores and ANTI-Vea outcomes. Additional subsidiary correlations were performed between the FFMQ and two self-report measures assessing subjective attentional control and mind-wandering. Benjamini-Hochberg was applied to control de type I error rate. Internal consistency reliability indices were estimated for all measures used to aid the interpretation of the correlational results.

Results Higher non-reactivity predicted overall faster reaction times and higher accuracy in attentional networks trials. Higher non-reactivity, as well as higher FFMQ total score, predicted faster reaction time and fewer lapses in arousal vigilance trials, the latter also being negatively associated with describe scores. The magnitude of the correlations ranged from $\tau_b = .103$ to $\tau_b = .119$. We found no association between FFMQ scores and executive control or executive vigilance.

Conclusions Our results indicate that dispositional mindfulness is linked to improved global attentional and arousal vigilance performance, being non-reactivity to inner experience the key facet driving the association. The absence of association to executive processes is discussed based on the high cognitive demands of the ANTI-Vea task.

Pretrial Registration Open Science Framework, https://osf.io/gb6c7

Keywords Mindfulness · Non-reactivity · Attentional networks · Executive vigilance · Arousal vigilance · Individual differences

Attention is one of the core components of the construct of mindfulness in virtually all theoretical and psychometric models proposed to date (Baer, 2019; Bishop et al., 2004; Brown & Ryan, 2003; Hölzel et al., 2011; Lutz et al., 2008; Malinowski, 2013). Although different conceptualizations of dispositional mindfulness emphasize different particular aspects, most of them generally conceive it as a trait-like (yet modifiable) tendency to (1) attend to present moment experience while (2) having an attitude of acceptance towards it. These two aspects have been termed as the "what" (attentional monitoring) and "how" (accepting attitude) of mindfulness (Baer, 2019). Apart from some exceptions (see, e.g., Levinson et al., 2014), dispositional mindfulness is most commonly assessed through self-report measures, such as the Mindfulness Attention Awareness Scale (MAAS; Brown & Ryan, 2003) and the Five Facets Mindfulness Questionnaire (FFMQ; Baer et al., 2006).

While essential to mindfulness, attention is not a simple nor a single neurocognitive process but rather a complex collection of them (Hommel et al., 2019). In fact, a host of theoretical proposals within cognitive psychology

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✉ Luis Cásedas
luiscasedas@ugr.es

[1] Mind, Brain and Behavior Research Center (CIMCYC), University of Granada, Granada, Spain

[2] Department of Experimental Psychology, University of Granada, Granada, Spain

[3] Department of Personality, Assessment and Psychological Treatments, University of Valencia, Valencia, Spain

and neuroscience has been advanced in trying to explain such complexity. Among them, one highly integrative and widely renowned proposal is Posner and Petersen's (1990) attentional networks model. The attentional networks model divides human attention into three differentiable, yet interdependent, neurocognitive systems: alertness, orienting, and executive control. The alertness network is composed of the locus coeruleus and the right frontoparietal cortex, and underpins the functions of phasic alertness (i.e., the capacity to increase arousal momentarily in response to a sudden event) and tonic alertness or vigilance (i.e., the capacity to sustain attention for a prolonged period). In turn, the orienting subsystem is implemented in the pulvinar nuclei of the thalamus, the superior colliculus, the frontal eye fields, and the posterior parietal cortex, and is responsible for the allocation of attention towards potentially relevant locations or sensory modalities. Finally, the executive control network extends mainly over the dorsolateral prefrontal and anterior cingulate cortices, and enables flexible monitoring and control of attention in the adaptation of behavior to long-term goals (Petersen & Posner, 2012; Posner & Petersen, 1990).

While also part of the alertness network in Posner and Petersen’s model, the capacity to sustain attention during extended periods—vigilance—has its own theoretical entity and explanatory models. There are two classic, competing explanations of the vigilance decrement phenomenon: the resources-depletion (or overload) account and the mindlessness (or underload) account. While the former understands the attentional system as a limited pool of resources that are depleted over time, the latter posits that monotonous, repetitive tasks (such as those assessing vigilance) are understimulating and lead to attention disengagement from task-relevant stimuli (Fortenbaugh et al., 2017). Recently, an alternative theoretical proposal, known as the resource-control account of sustained attention, has been developed to encompass the results predicted by both previous models (Thomson et al., 2015). Under this framework, available resources do decline, but not because they are depleted. Instead, they are increasingly redirected from external stimuli to mind-wandering (which is understood as the mind’s default state), while it is executive control, needed to redirect and maintain resources onto the relevant task, the function that wanes over time. Finally, an even more recent account argues the aforementioned progressive decay of executive control to be driven by motivational factors, while also proposes arousal as a key variable in sustaining attention, so that too high or too low arousal levels would lead to suboptimal vigilance performance (Esterman & Rothlein, 2019).

Considering these theoretical perspectives, dispositional mindfulness may be related to the functioning of the attentional networks and vigilance in at least three different ways. First, the attention monitoring quality of dispositional mindfulness is known to involve the voluntary engagement, disengagement, and reengagement of awareness with the multiple elements of experience (Lutz et al., 2008). Arguably, this entails a primarily executive process highly related to executive control. Second, the characteristic “present moment” quality of mindful attention is juxtaposed with the perceptual decoupling that occurs during mind-wandering. As a result, higher levels of dispositional mindfulness may facilitate sustaining attention to external stimuli during extended periods of time, i.e., vigilance (possibly in parallel to an increased efficiency of the executive control network; Thomson et al., 2015). Finally, the accepting and non-reactive attitude towards inner experience involved in dispositional mindfulness may enable an individual to deploy attentional resources more efficiently in contexts involving stress, fatigue, or any other feature that is linked to negative affectivity. Although speculative, this may in turn relate to executive control and vigilance functioning, given that engagement in both of these processes is well known to result aversive in itself (Kurzban, 2016).

Several cognitive-behavioral tasks have been devised to assess attentional networks and vigilance performance. Regarding the attentional networks, these include the pioneer and widely used Attentional Networks Test (ANT; Fan et al., 2002), as well as posterior modifications such as the ANT for Interactions (ANTI; Callejas et al., 2004). Using an arrows flanker paradigm (Eriksen & Eriksen, 1974) that incorporates spatial cues and warning signals, these tasks are well suited to simultaneously evaluate executive control, orienting, and phasic alertness (i.e., the classic attentional networks). However, they are not suitable to evaluate tonic alertness (i.e., vigilance). To assess vigilance, other specific tasks have been developed, in which participants are classically required to remain attentive to detect critical events during extended periods. These assessments include, among others, the Sustained Attention to Response Task (SART; Robertson et al., 1997), the Continuous Performance Test (CPT; Conners 2000), or the Psychomotor Vigilance Task (PVT; Lim & Dinges, 2008).

Excitingly, a novel experimental task has been developed in recent years to evaluate both the attentional networks and vigilance, simultaneously: the ANT for Interactions and Vigilance—executive and arousal components (ANTI-Vea; Luna et al., 2018). This comprehensive experimental assessment, moreover, is built upon the theoretical assumption that vigilance itself may not be a unitary function, but could be composed of two distinct processes (Oken et al., 2006). While the first process would involve the capacity to maintain an executive control set for target selection of critical events over time (as assessed, e.g., in the ANTI-V, SART, or CPT), the second process would entail the maintenance of a level of arousal that allows quick response to the environment without exerting much control (as assessed in the PVT). In considering this distinction, the ANTI-Vea thus assesses phasic alertness, orienting, and executive control, while simultaneously tapping into both executive vigilance (EV) and arousal vigilance (AV). Furthermore, the task provides two additional measures indexing global attentional performance (i.e., average processing speed and accuracy across all attentional networks conditions). Successfully validated for both laboratory and online testing (Luna et al., 2021), the ANTI-Vea is arguably one of the most comprehensive assessments of the human attention system to date.

Notwithstanding the fundamental role that attentional processes may play in the psychological construct of mindfulness, little research has examined the relationship between objective (sustained) attentional performance (as measured using ANT-related or vigilance tasks) and dispositional mindfulness (as measured by self-report, most commonly the MAAS or FFMQ). This contrasts with research conducted on the relationship between attention and mindfulness training, for which there is a larger body of published literature (while delving into the state-of-the-art of the mindfulness training literature is beyond the scope of the present introduction, we direct interested readers to the recent meta-analyses by Whitfield et al., 2021, and Zainal & Newman, 2021). To our knowledge, there are only 13 published studies tackling the relationship of dispositional mindfulness with attentional networks and vigilance performance; and their results show little consistency. This is especially noticeable regarding the classic attentional networks, for which higher self-reported dispositional mindfulness has been linked to improved executive control (Ainsworth et al., 2013; Tsai & Chou, 2016); to enhanced phasic alertness and reduced orienting (Di Francesco et al., 2017); to enhanced orienting (Isbel & Mahar, 2015); and to none of the attentional networks or only interactions among them (Jaiswal et al., 2018; Sørensen et al., 2018; Wittmann et al., 2014). Regarding vigilance, previous research has found several positive associations between task performance and dispositional mindfulness (Cheyne et al., 2006; Josefsson & Broberg, 2011; Lara et al., 2014; Rice & Liu, 2017; Schmertz et al., 2009). However, effect sizes differed substantially among studies (from Pearson's $r = 0.13$ to $r = 0.51$) and null findings were also reported in nearly all of them (Josefsson et al., 2011; Lara et al., 2014; Rice & Liu, 2017; Schmertz et al., 2009). Moreover, one study did not find any association at all (Rahl et al., 2017).

Also of note, most previous studies were relatively small. Excluding one unusually large study ($N = 504$; Cheyne et al., 2006), the average sample size throughout them is 80 participants. While this is already a meritorious sample that may lead to reasonable statistical power in other types of study designs, it may arguably not be sufficient for individual differences (i.e., correlational) research (Schönbrodt & Perugini, 2013). This holds especially true considering that most statistically significant findings were found within the small-to-medium size range, i.e., around $r = 0.20$ (Ainsworth et al., 2013; Cheyne et al., 2006; Di Francesco et al., 2017; Josefsson & Broberg, 2011; Rice & Liu, 2017). In fact, assuming a correlation of 0.20 (and setting alpha at 0.05), the statistical power achieved with a sample of 80 participants is 0.43 (Faul et al., 2009). Given that low power renders both low probability of observing effects that do exist (i.e., high probability of type II errors) and high probability for observed significant effects to be false positives (Forstmeier et al., 2017), this may be one critical factor explaining the aforementioned pattern of mixed results.

Based on the above considerations, we conducted the present preregistered study aiming to examine the existence and strength of the relationship between dispositional mindfulness and objective attentional (i.e., phasic alertness, orienting, and executive control) and vigilance performance, while testing a sufficiently powered sample of participants. In particular, we set out to correlate scores on FFMQ with objective performance in the ANTI-Vea. As described in greater detail in the preregistration, we hypothesized higher dispositional mindfulness to predict better executive control, executive vigilance, and global attentional performance (i.e., overall faster processing speed and/or lower error rate), while no hypotheses were formulated regarding phasic alertness, orienting, or arousal vigilance. As a subsidiary goal, we additionally set out to explore the relationship between dispositional mindfulness scores and two self-report measures of attention, namely the Attentional Control Scale (ACS; Derryberry & Reed, 2002) and the Mind-Wandering Deliberate and Spontaneous scales (MW-D and MW-S; Carriere et al., 2013).

Methods

Participants

G*Power 3.1 (Faul et al., 2009) was used to estimate the sample size needed given our study design. We expected some of the effects under investigation to be around $r = 0.20$, as found in several previous studies correlating self-reported dispositional mindfulness and cognitive-behavioral tasks assessing attentional networks or vigilance (e.g., Ainsworth et al., 2013; Cheyne et al., 2006; Di Francesco et al., 2017; Josefsson & Broberg, 2011; Rice & Liu, 2017). In order to detect a two-tailed Pearson correlation of 0.20, setting the significance level at 0.05 and the statistical power at 0.80, the estimated sample size needed in our study was 193 participants. Based on this a priori calculation, we aimed at testing a sample of at least 200 subjects.

Participants were invited using the institutional e-mail distribution lists of the University of Granada and participated in exchange of course credit (in case they were undergraduate psychology students) or monetary compensation (in case they were students from other programs or university staff). Three hundred forty-seven participants completed the full set of self-report measures and provided valid cognitive-behavioral performance data. Of them, those who met a prespecified, exhaustive set of eleven selection criteria were included in the analysis. We devised these criteria aiming to (1) standardize the sample and remove confounding variables that could potentially affect our data (C1–9) and (2) control for artifacts derived from a biased interpretation of self-report items (C10–11). The selection criteria and number of participants qualifying for exclusion in each case are provided in Fig. 1. A total of 219 participants (aged between 18 and 34 years; mean age = 23.37; SD = 3.64; 68.49% female) met all criteria and were included in the study.

Procedure

Participants were reached through e-mail. By following a link, they could access the first part of the study that consisted of an online survey hosted on LimeSurvey (http://www.limesurvey.org). Once accessed, and prior to starting the experimental procedure, participants received basic information about the study and gave informed consent. Next, they were presented with an eligibility battery comprised of sociodemographic, health-related, and lifestyle questions. Next, participants completed the FFMQ (Cebolla et al., 2012), the ACS (Derryberry & Reed, 2002), as well as the MW-D and MW-S (Carriere et al., 2013) scales. By the end of the survey, participants were invited to follow another link to the webpage hosting the ANTI-Vea (https://www.ugr.es/~neurocog/ANTI/).

At the ANTI-Vea webpage, and before beginning with the task, participants were encouraged to reduce any possible distractions from then onwards. A message also warned them that the task would be displayed full-screen and that it was important to perform the entire procedure with no interruptions. Additionally, they were asked to configure the computer's sound level at 75%, use no headphones, and turn off the sound and vibration function on their mobile phone. They were also encouraged to keep the phone out of reach until the end of the task. Moreover, they were asked to turn off any entertainment device, such as television, radio, or music players. Immediately before starting the ANTI-Vea, participants were invited to take a break if it was needed for any particular reason and were encouraged to remain seated thereafter until completion of the task.

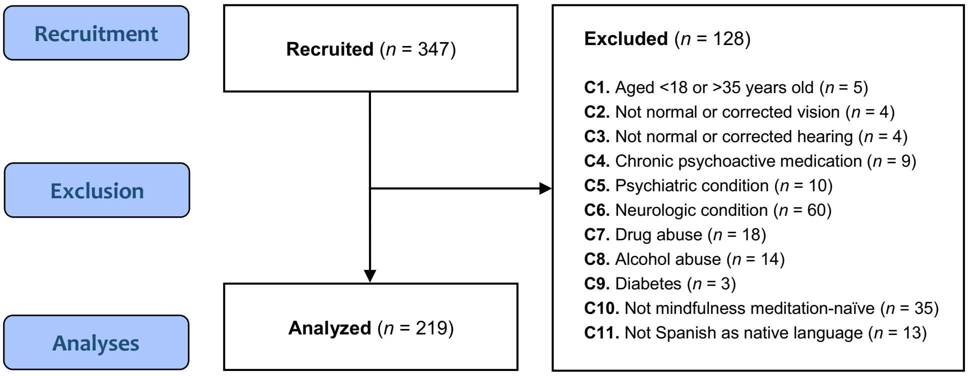
The ANTI-Vea comprises three types of trials: ANTI (measuring the attentional networks; 60%), EV (measuring executive vigilance; 20%), and AV (measuring arousal vigilance; 20%). In ANTI trials, participants performed a flanker task that was sometimes preceded by a warning tone and or a visual cue (or both), in order to assess phasic alertness (no tone minus tone condition), orienting (invalid minus valid cue condition), and executive control (incongruent minus congruent condition). In EV trials, the target (central arrow) was upwardly or downwardly displaced, and participants had to detect this minor change. In AV trials, a red millisecond countdown was presented, in which participants were instructed to stop as fast as possible. For a schematic representation of the ANTI-Vea task procedure in each trial type, see Fig. 2 (a detailed description of the procedure is provided in Supplementary Material S1). The ANTI-Vea started with a practice phase, in which instructions were given so that participants could gradually familiarize themselves with each type of trial. Next, six blocks of 80 randomized trials each (48 ANTI, 16 EV, and 16 AV) were presented, without any break, as the actual experimental task. Participants were encouraged to respond as quickly and accurately as possible while keeping their eyes on the fixation cross until the finalization of the task.

Measures

Five Facets Mindfulness Questionnaire

Our primary self-report measure was the Spanish version of the FFMQ (Cebolla et al., 2012), a 39-item scale assessing

Fig. 1 Participant's flow diagram and selection criteria including number of subjects qualifying for exclusion in each case. Note that a proportion of participants qualified for exclusion by more than one criteria, reason why the sum of *n* by criteria surpass the 128 participants excluded



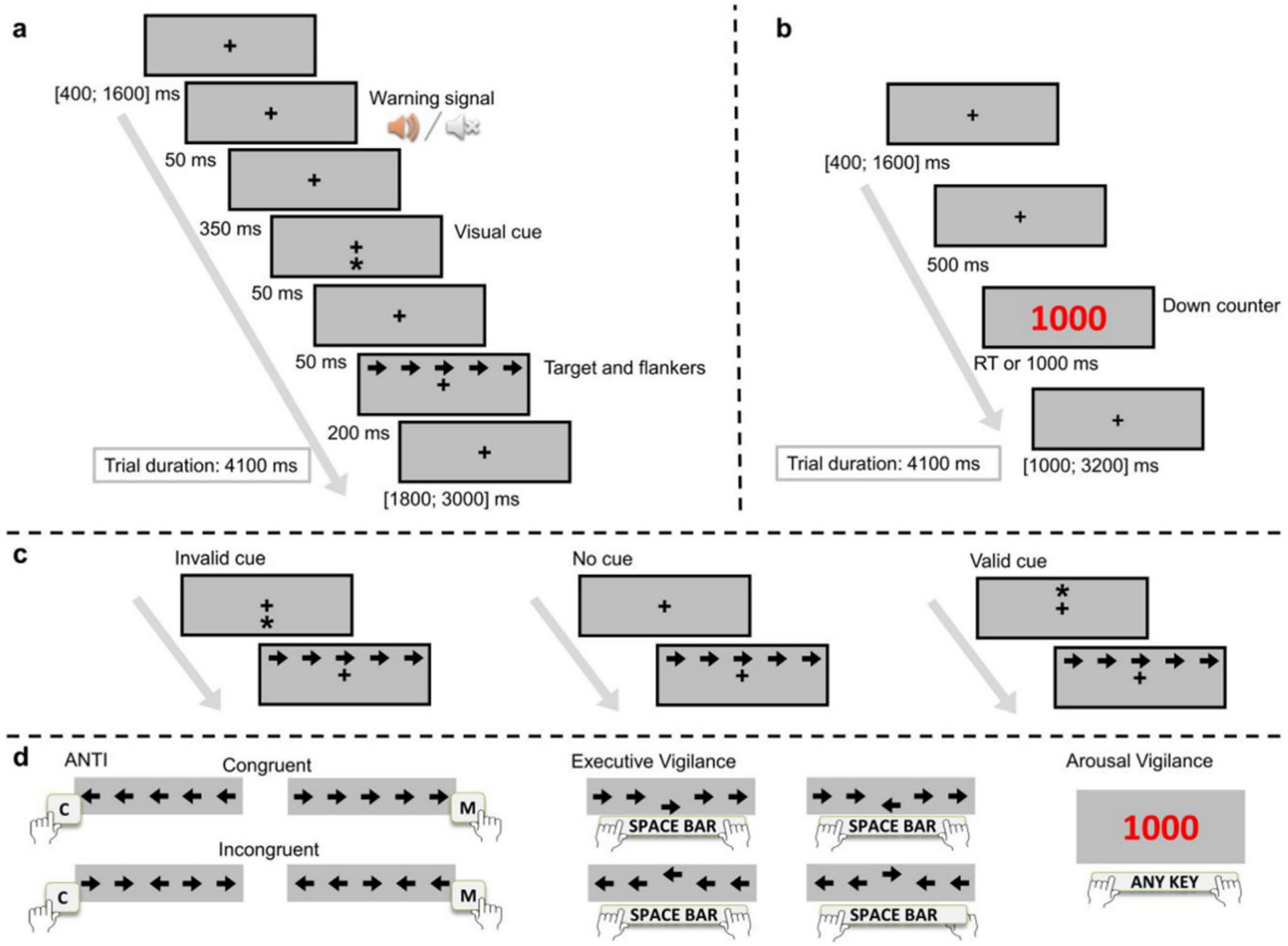


Fig. 2 Visual representation of the ANTI-Vea task procedure. **a** Stimuli sequence for ANTI and EV trials, during which participants had either to respond to the direction pointed by the central arrow or to detect its vertical displacement, respectively. **b** Stimuli sequence for AV trials, during which participants had to stop the red countdown as fast as possible. **c** Examples of the three visual cue conditions for the assessment of the orienting network. **d** Correct responses for each type of trial

five component factors of mindfulness. (1) Observing (hereafter referred to as Observe) regards attending to and noticing internal and external experiences such as sensations, emotions, and thoughts. (2) Describing (Describe) refers to labeling internal experiences, especially emotions, with words. (3) Acting with awareness (Actaware) is defined as the capacity to being focused on present-moment activities as opposed to behaving reflexively or getting distracted. (4) Non-judging of inner experience (Nonjudge) refers to adopting a non-evaluative attitude toward thoughts and feelings. And (5) non-reactivity to inner experience (Nonreact) regards experiencing thoughts and feelings without reflexively responding nor being caught up by them. FFMQ items are rated on a 5-point Likert scale ranging from 1 ("never or very rarely true") to 5 ("very often or always true"). In our study, the reliability of the instrument was similar to that found in previous research, yielding estimates of internal consistency (α for Cronbach's alpha and ω for McDonald's omega) as follows: for Observe, $\alpha = 0.68$, $\omega = 0.69$; for Describe, $\alpha = 0.91$, $\omega = 0.92$; for Actaware, $\alpha = 0.88$, $\omega = 0.88$; for Nonjudge, $\alpha = 0.90$, $\omega = 0.90$; for Nonreact, $\alpha = 0.76$, $\omega = 0.77$; and for the Total score, $\alpha = 0.85$, $\omega = 0.86$. The items of the Spanish version of the FFMQ are provided as Supplementary Material S2.

Attentional Control Scale

Participants additionally completed the Spanish translation of the ACS (Derryberry & Reed, 2002). The ACS comprises 20 items assessing general everyday attentional control ability. Items are rated on a 4-point Likert scale from 1 ("almost never") to 4 ("always"). In the present study, the internal consistency of the instrument was $\alpha = 0.84$, $\omega = 0.84$. The items of the Spanish translation of the ACS are provided as Supplementary Material S3.

Mind-Wandering Deliberate and Spontaneous Scales

As the last self-report measure, participants completed the Spanish translation of the MW-D and MW-S (Carriere et al., 2013). The MW-D and MW-S comprise four items each and assess everyday tendencies to engage in task-unrelated thought or mind-wandering either voluntarily or involuntarily, respectively (Carriere et al., 2013). Items are scored on a 7-point Likert scale from 1 ("rarely") to 7 ("a lot") except for the third item of the MW-S (1 = "almost never" to 7 = "almost always") and the third item of the MW-D (1 = "not at all true" to 7 = "very true"). In our study, the MW-D and MW-S yielded internal consistency estimates of $\alpha = 0.86$, $\omega = 0.86$, and $\alpha = 0.80$, $\omega = 0.80$, respectively. The items of the Spanish translation of the MW-D and MW-S scales are provided as Supplementary Material S4.

ANTI-Vea Task

Cognitive-behavioral attentional and vigilance data were collected using the online version of the ANTI-Vea (Luna et al., 2018), which is available for free use in multiple languages at https://www.ugr.es/~neurocog/ANTI/. The stimulus characteristics for each trial type are depicted in Fig. 2 (further technical specifications are provided in Supplementary Material S1). The ANTI-Vea has recently been validated for both in-lab and online testing (Luna et al., 2021). As demonstrated by Luna et al. (2021), there are no substantial differences between the data collected by each version of the task. Moreover, in both cases, the ANTI-Vea (1) demonstrated to be at least as reliable as previous versions of the task such as the classic ANT for the assessment of the attentional networks, while (2) demonstrating high reliability for assessing the executive and arousal components of vigilance. The reliability of the ANTI-Vea in the present study was also estimated by computing split-half internal consistency estimates based on our collected data.

Data Analyses

ANTI-Vea Analysis

Following standard analysis of the ANTI-Vea task (Luna, Barttfeld, et al., 2020; Luna, Telga, et al., 2020), reaction time (RT) analysis in ANTI trials excluded incorrect responses or trials with RT below 200 ms or above 1500 ms. Data from participants with an error rate larger than 25% or with extreme average RT (± 2.5 standard deviations [SD] from the group mean) in ANTI trials were also excluded. Additionally, we removed participants with extremely low hit rate or extremely high lapse rate (± 2.5 SD from the group mean), as such rates were interpreted not as just poor performance but as indicative of participants not being actually engaged in the task. Lastly, one participant was excluded for which 80 trials were not registered due to technical reasons. Since it has been previously shown that four blocks are sufficient to reliably measure the attentional networks and to detect decrements changes in sustained attention (Román-Caballero et al. 2021), participants were included in the analysis if they had performed the task at least until the end of the fourth experimental block (out of the total sample of 219 participants, 202 [92.2%] performed the task at least until end the fifth experimental block, and 191 [87.2%] completed the full ANTI-Vea procedure).

Once the data were preprocessed, separate analyses were conducted for ANTI, EV, and AV trials. For ANTI trials, we computed: (1) the mean RT and percentage of errors (as global indices of attentional performance); and the efficiency indices for (2) phasic alertness (no tone minus tone, in no cue trials), (3) orienting (invalid minus valid trials), and (4) executive control (incongruent minus congruent trials) using both RTs and percentage of errors. For EV trials, we computed the following measures: (1) hits (correctly identified vertically displaced target); (2) false alarms (non-displaced target assessed as being vertically displaced); (3) A' (sensitivity); and (4) B'' (response bias). For each of them, we obtained both overall indices and decrement slope indices. The overall indices are average measures throughout the task. In turn, the decrement slope indices are measures of the extent of change over time. In particular, to obtain the decrement slopes, we calculated the slope of the regression line for each participant across the six blocks of trials in each vigilance measure. Lastly, regarding AV trials, we computed both overall indices and decrement slopes for (1) mean RT, (2) SD of RTs, and (3) percentage of lapses (defined as the percentage of AV trials with responses > 600 ms or with no response).

Correlational Analysis

Correlational analyses were conducted (1) between FFMQ and the indices computed from ANTI, EV, and AV trials, and (2) between FFMQ and the ACS, MW-D, and MW-S scales. First, the assumption of normality was tested by using Shapiro–Wilk (Shapiro et al., 1968). Given that virtually none of the pairs of variables of interest was bivariate normally distributed, we used Kendall's Tau for analysis, as it is considered the most robust correlation coefficient in cases of non-parametric data (Croux & Dehon, 2010). Note that the interpretation of Kendall's Tau magnitude differs from that of Pearson's *r*. While values of 0.10, 0.30, and 0.50 are commonly considered as small, medium, and large Pearson correlations, the equivalent values for Kendall correlation are 0.07, 0.20, and 0.35, respectively (for a table of conversion among correlation coefficients, see Gilpin, 1993).

One-tailed correlations were applied to contrasts for which we had preregistered directional hypotheses (i.e., regarding executive control, executive vigilance, and global attentional performance). In particular, we applied one-tailed tests for positive correlations to variables indexing good performance (hits and A') or that decrease over time in task (hits slope, A' slope, FA slope); conversely, we applied one-tailed tests for negative correlations to variables indexing poor performance (interference control effect, FAs, overall RT, overall percentage of errors) or that increase over time in task (B'' slope). Two-tailed correlations were conducted for all remaining contrasts. In addition, the set of correlations as conducted applying two-tailed tests to all contrasts is provided as Supplementary Information. Alpha (significance level) was set at 0.05. Finally, Benjamini–Hochberg correction for multiple comparisons was applied (Benjamini & Hochberg, 1995) setting the FDR at 0.20 (McDonald, 2014). We used JASP 0.13.1 (JASP Team, 2020) to conduct the correlations and Jamovi 1.1.9 (Jamovi Project, 2020) to generate the corresponding scatter plots.

Reliability Analysis

To aid the interpretation of our correlational results, we considered recent discussions highlighting the criticality of assessing measurement reliability when conducting individual differences research (e.g., Dang et al., 2020; Parsons et al., 2019). As any observed correlation is constrained by the reliability of the measures used to obtain it, so that $\text{Sample correlation} = \text{True correlation} \times \sqrt{\text{Reliability (x)} \times \text{Reliability (y)}}$ (Dang et al., 2020), without reliability estimates, it is not possible to ascertain whether the size of a given correlation reflects the actual shared variance or is rather a byproduct of measurement error. We thus computed internal consistency indices for all measured used. For self-report assessments, we obtained both Cronbach's alpha and McDonald's omega coefficients (Peters, 2014). Regarding the ANTI-Vea, we computed 10,000-iterations permutation-based split-half reliability indices with Spearman-Brown correction, for both overall and decrement slope assessments. The rationale of the split-half reliability method has been described by Parsons et al. (2019), while its procedure as applied to the ANTI-Vea task has been detailed by Luna et al. (2021). The analysis was conducted in RStudio 1.1.463 (RStudio Team, 2020). The script used was adapted from the original version by Luna et al. (2021) and is available at the Open Science Framework (https://osf.io/374rs/).

Results

Attentional Networks and Vigilance

Descriptive statistics and split-half reliability indices for ANTI, EV, and AV outcomes are provided in Table 1. As shown, the task yielded indices in line with those reported by Luna et al. (2021) regarding both the attentional and vigilance measurements and their reliability estimates. Additional analyses were conducted to be certain that our EV and AV indices were appropriately assessing the vigilance decrement phenomenon. As detailed in Supplementary Material S5, a series of repeated measures ANOVAs confirmed that all the EV and AV measures were sensitive to detect performance changes across time on task. Our main research outcomes are summarized in Table 2, where correlations between FFMQ scores and ANTI, EV, and AV outcomes are reported. For the sake of simplicity, herein, we only report *p*-values of significant findings. *p*-values obtained for all significant and non-significant comparisons performed between FFMQ scores and ANTI, EV, and AV outcomes are provided as Supplementary Material S6.

Table 1 Descriptive statistics and split-half reliability indices (Spearman-Brown corrected) of ANTI-Vea outcomes

	M	*SD*	r_{SB}
Attentional networks			
RT overall	629	85	0.99
% errors overall	6.01	4.51	0.91
RT alerting	43	41	0.45
% errors alerting	1.30	4.56	0.24
RT orienting	45	27	0.40
% errors orienting	0.14	3.71	0.22
RT control	38	28	0.64
% errors control	0.01	3.71	0.51
Executive vigilance			
% hits	80.40	12.83	0.91
% hits slope	−1.79	3.22	0.58
% FAs	6.84	6.04	0.78
% FAs slope	−0.37	2.16	0.21
A'	0.93	0.04	0.84
A' slope	−0.004	0.01	0.45
B''	0.41	0.43	0.80
B'' slope	0.05	0.16	0.06
Arousal vigilance			
RT mean	490	55	0.96
RT mean slope	5.44	10.74	0.65
% lapses	9.49	12.79	0.96
% lapses slope	1.54	3.14	0.81
SD of RT	78.27	26.71	0.71
SD of RT slope	4.03	9.59	0.65

M, mean; *SD*, standard deviation; r_{SB}, split-half reliability (Spearman-Brown corrected); *RT*, reaction time; *FA*, false alarm.

The reliability of the ANTI outcomes ranged from $r_{\text{SB}} = 0.22$ to $r_{\text{SB}} = 0.99$, with the global indices of attention demonstrating higher reliability ($r_{\text{SB}} = 0.91$ to $r_{\text{SB}} = 0.99$) than the efficiency scores ($r_{\text{SB}} = 0.22$ to $r_{\text{SB}} = 0.64$; see Table 1). We found seven correlations between FFMQ and attentional networks outcomes, of which two remained significant after Benjamini–Hochberg correction for multiple comparisons (see Table 2). In particular, scores on Nonreact facet were negatively associated to overall RTs, $\tau_b = -0.118$, $p = 0.006$, and percentage of errors, $\tau_b = -0.118$, $p = 0.006$, in ANTI trials (see also Fig. 3). In line with our hypotheses, these results indicate that participants reporting higher dispositional mindfulness—particularly those less predisposed to react reflexively to negative thoughts and emotions—showed better global attentional performance as indexed by faster and more accurate responses to the task.

Concerning EV outcomes, reliability estimates ranged from $r_{SB} = 0.06$ to $r_{SB} = 0.91$, with overall indices showing higher reliability ($r_{SB} = 0.78$ to $r_{SB} = 0.91$) than decrement slope scores ($r_{SB} = 0.06$ to $r_{SB} = 0.58$; see Table 1). Of the correlations performed, two of them were initially found to be significant. However, none of them was maintained as true positives after performing Benjamini–Hochberg correction for multiple comparisons (see Table 2).

In contrast, five correlations were found between AV and FFMQ scores, all of which remained significant after correcting for multiple comparisons (see Table 2). Split-half reliability ranged from $r_{SB} = 0.65$ to $r_{SB} = 0.96$ for AV outcomes. As for EV, overall indices demonstrated higher reliability ($r_{SB} = 0.71$ to $r_{SB} = 0.96$) than decrement slope scores ($r_{SB} = 0.65$ to $r_{SB} = 0.81$; see Table 1). Correlational results showed that scores on Describe facet were negatively associated with number of lapses, $\tau_b = -0.111$, $p = 0.019$, while scores on Nonreact were negatively associated with both mean RT in AV trials, $\tau_b = -0.119$, $p = 0.011$, and percentage of lapses, $\tau_b = -0.107$, $p = 0.026$ (see also Fig. 3). Moreover, total FFMQ scores also correlated negatively with mean RT in AV trials, $\tau_b = -0.103$, $p = 0.025$, and number of lapses, $\tau_b = -0.103$, $p = 0.027$. These results indicate that participants with higher self-reported dispositional mindfulness showed improved arousal vigilance as indexed by faster responses and fewer lapses (i.e., missed targets) in AV trials.

Table 2 Kendall's Tau correlations between Five Facets Mindfulness Questionnaire and attentional networks, executive vigilance, and arousal vigilance outcomes

	Five Facets Mindfulness Questionnaire					
	Observe	Describe	Actaware	Nonjudge	Nonreact	Total
Attentional networks						
RT overall	−0.055	−0.014	−0.016	−0.029	−0.118**	$-0.078^{\#}$
% errors overall	0.010	−0.054	0.005	−0.012	−0.118**	$-0.078^{\#}$
RT alerting	−0.035	0.025	$0.095^{\#}$	−0.014	−0.020	0.011
% errors alerting	−0.031	−0.026	$0.101^{\#}$	0.011	−0.029	0.017
RT orienting	−0.002	0.012	−0.035	−0.040	$0.104^{\#}$	−0.008
% errors orienting	−0.020	−0.041	−0.062	−0.077	−0.023	−0.075
RT control	−0.014	−0.024	0.083	0.006	−0.025	0.012
% errors control	−0.001	−0.009	0.058	0.031	0.054	0.044
Executive vigilance						
% Hits	−0.066	0.049	0.013	−0.009	0.010	0.012
% Hits slope	0.008	−0.013	−0.026	0.041	−0.033	0.006
% FAs	0.011	0.033	−0.022	−0.018	−0.027	−0.019
% FAs slope	−0.027	−0.030	0.046	0.029	−0.005	0.020
A'	−0.090	0.025	−0.007	−0.008	0.025	−0.002
A' slope	0.007	0.004	−0.012	0.027	0.016	0.002
B''	0.045	−0.032	0.017	0.013	0.019	0.026
B'' slope	−0.042	0.023	−0.058	$-0.078^{\#}$	−0.044	$-0.096^{\#}$
Arousal vigilance						
RT mean	0.052	−0.091	−0.033	−0.060	−0.119*	−0.103*
RT mean slope	0.043	0.034	0.015	−0.010	−0.059	0.005
% lapses	0.034	−0.111*	0.010	−0.059	−0.107*	−0.103*
% lapses slope	0.026	−0.042	−0.008	−0.082	−0.058	−0.070
SD of RT	0.018	−0.039	0.034	−0.022	−0.079	−0.043
SD of RT slope	0.001	−0.031	−0.004	−0.046	−0.062	−0.049

$N = 219$. *RT*, reaction time; *FA*, false alarm; *SD*, standard deviation. Number sign (#) indicates correlations declared significant ($p < 0.05$) prior to Benjamini–Hochberg procedure. Asterisks (*) indicate correlations held significant after Benjamini–Hochberg procedure.

* $p < 0.05$; ** $p < 0.01$.

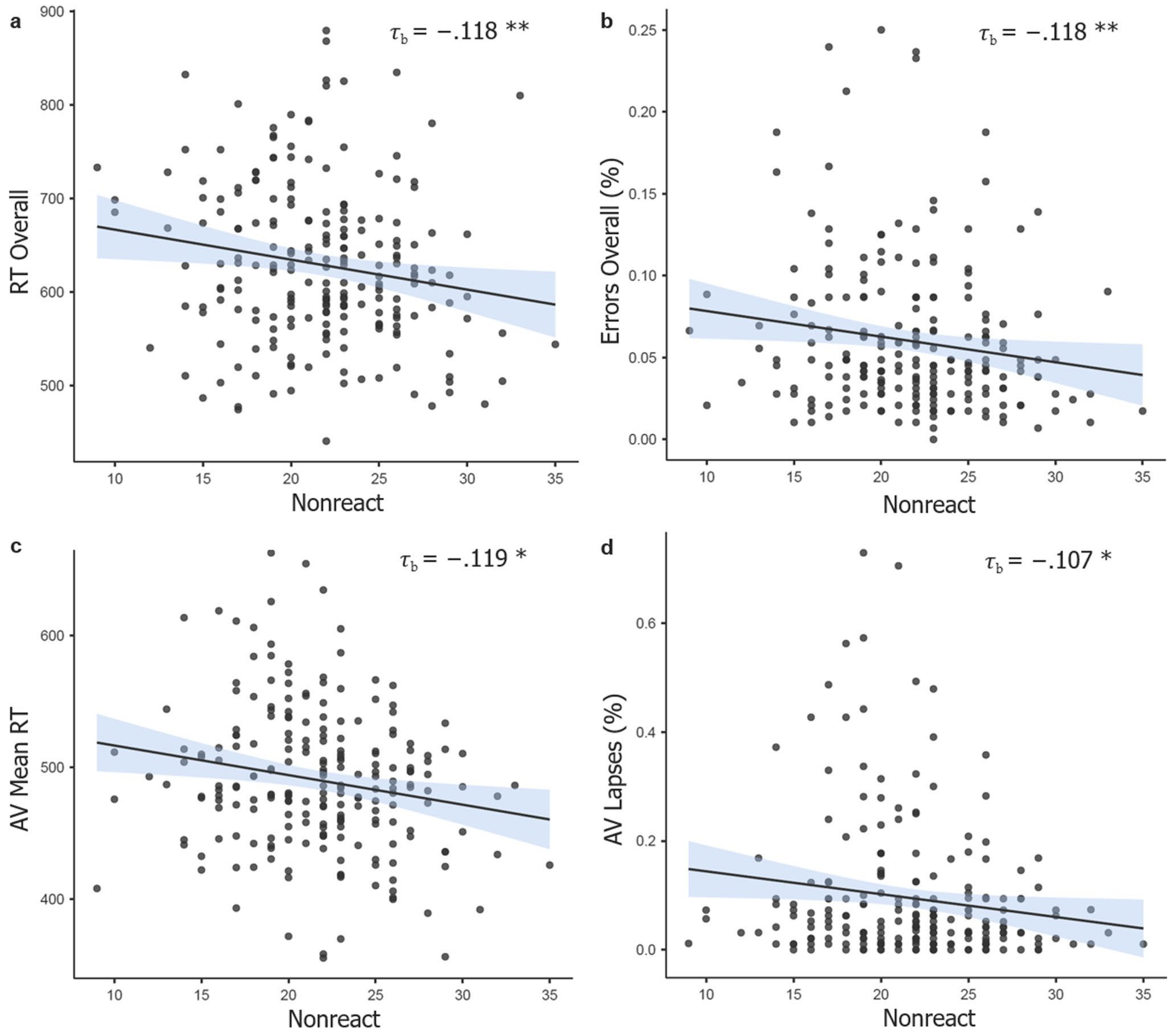


Fig. 3 Main correlational results of the study. Scatter plot and correlation between Nonreact score and **a** mean RT across ANTI trials; **b** mean error rate across ANTI trials; **c** RT in AV trials; and **d** lapses rate in AV trials. Correlations estimated using Kendall's Tau coefficient. Reported *p*-values are after applying Benjamini–Hochberg procedure. Shading represents standard errors. $N = 219$

As shown in Supplementary Material S7, the results applying two-tailed tests to the full set of correlations were virtually identical to those reported above. As the only exception, the two correlations between Nonreact and the global attentional indices, albeit also declared significant, did not hold after correction for multiple comparisons when bidirectional testing was applied.

Finally, and in addition to our planned comparisons, a series of post hoc correlational analyses were conducted to further scrutinize the relationship between dispositional mindfulness and attentional performance. In particular, we examined the relationship between attentional performance and dispositional mindfulness at the first half (i.e., blocks 1–3) and the second half (i.e., blocks 4–6) of the task, separately. The rationale for this analysis was to investigate potential changes in attentional networks performance in relation to mindfulness trait as a function of time on task. Note that while the AV and EV measures can capture such a potential change during time on task by means of the decrement slopes, this is not the case for the attentional networks indices. The results from these exploratory analyses along with a narrative overview and interpretation of them are provided as Supplementary Material S8.

Self-Reported Attentional Control and Mind-Wandering

Secondary research outcomes are summarized in Table 3, where correlations between FFMQ and ACS, MW-D, and MW-S scores are reported. After correction for multiple

Table 3 Kendall's Tau correlations between Five Facets Mindfulness Questionnaire and ACS, MW-S, and MW-D

	Five Facets Mindfulness Questionnaire					
	Observe	Describe	Actaware	Nonjudge	Nonreact	Total
ACS	0.004	0.197***	0.366***	0.193***	0.163***	0.336***
MW-D	0.149**	− 0.013	− 0.137**	− 0.039	0.075	− 0.013
MW-S	0.184***	− 0.111*	− 0.434***	− 0.247***	− 0.091	− 0.264***

$N = 219$. *ACS*, Attentional Control Scale; *MW-S*, Mind-Wandering Spontaneous; *MW-D*, Mind-Wandering Deliberate. Asterisks (*) indicate correlations held significant after Benjamini–Hochberg procedure.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

comparisons, we found that FFMQ total score correlated positively with ACS, $\tau_b = 0.336$, $p < 0.001$, and negatively with MW-S, $\tau_b = -0.264$, $p < 0.001$ (while it was not related to MW-D, $\tau_b = -0.013$, $p = 0.781$). These results indicate that participants with higher dispositional mindfulness reported having a greater everyday attentional control ability and a reduced inclination to engage spontaneously in mind-wandering (while showed no different propensity to mind-wander voluntarily). For correlations between specific FFMQ facets and self-reported attentional control and mind-wandering, see Table 3. *p*-values obtained for all comparisons performed between FFMQ scores, ACS, and MW questionnaires are provided as Supplementary Material S9.

Discussion

The present study aimed to examine the existence and strength of the relationship between dispositional mindfulness and a variety of objective measures of attention and vigilance. To this end, FFMQ scores were correlated with attentional performance in a novel cognitive-behavioral assessment: the ANTI-Vea. As an additional aim, we also explored the relationships between dispositional mindfulness and two subjective attention-related measures (ACS and MW-D/MW-S). In order to buffer the influence of type I and type II error rates, we tested a large sample of participants ($N = 219$) and corrected for multiple comparisons using the Benjamini–Hochberg procedure. For all measures, reliability coefficients were computed to aid in the interpretation of our results.

As expected, our analyses revealed an association between global attentional performance and dispositional mindfulness. In particular, higher Nonreact scores predicted faster RT and reduced error rate in ANTI trials. Contrary to expectations, however, we did not find an association between dispositional mindfulness and executive vigilance. Instead, we found such a relationship with arousal vigilance, so that higher scores on Nonreact, as well as higher FFMQ total score, predicted faster RT and fewer lapses in AV trials. The number of lapses was also negatively correlated to Describe scores. Finally, we did not find the expected positive association between dispositional mindfulness and the efficiency of the executive control network (nor did we find any association with phasic alertness or orienting). Overall, this pattern of findings suggests that dispositional mindfulness is related to improved global attentional and arousal vigilance performance, with non-reactivity to inner experience as the main facet driving the association. The size of the effects was within the anticipated range, being on average of about Kendall's $\tau_b = 0.11$ (equivalent to Pearson's $r = 0.17$) for statistically significant correlations.

Non-reactivity was the facet most consistently and strongly associated with better objective attentional and vigilance performance. Interestingly, this indicates that a rather affective quality (i.e., not being reactive to the content of experience including thoughts and emotions and, thus, not being carried away by them) is more closely related to improved cognition than other more attention-related qualities (such as acting with awareness). This may be explained by considering the characteristics of the ANTI-Vea, which requires to perform (and switch among) three simultaneous tasks (ANTI, EV, and AV) throughout approximately 50 min. Being highly demanding and lengthy, the ANTI-Vea is experienced by participants as moderately aversive. As coping with stress requires cognitive resources (Muraven & Baumeister, 2000), our results seem to suggest that fewer reactive participants may have needed to invest fewer resources to downregulate the mild negative affect and associated automatic negative thoughts linked to task performance, thus being less overloaded by its cognitive demands. In turn, freeing up cognitive load would have translated into an improved general state of preparation during the task. This interpretation is in line with the fact that participants with higher non-reactivity scores were faster in responding to both ANTI and AV trials, assessments that index overall and sustained preparation throughout the task, respectively. Importantly, this association is not the result of a speed/accuracy trade-off since higher non-reactivity scores were also associated with a reduced error rate in ANTI trials.

These findings are consistent with several pieces of previous evidence. For instance, non-reactivity has been identified as the mindfulness facet most strongly associated with attentional accuracy in a breath counting task (Tortella-Feliu et al., 2020), and has been shown to be sensitive to the length of focused attention meditation practice (Cebolla et al., 2017). Furthermore, evidence shows that non-reactivity appears to be the best proxy for the broader construct of acceptance (Soler et al., 2014), which has also been shown to be critical for cognitive performance. In a randomized controlled study, Rahl et al. (2017) evaluated vigilance performance in the SART after two different mindfulness interventions that incorporated either training in attention monitoring or training in both attention monitoring and acceptance. The study found that the attention monitoring and acceptance training group showed higher discriminability throughout the task, thus outperforming the one based on attention monitoring training alone. Altogether, these and our own findings suggest that the "how" of mindfulness (accepting attitude) is at least as relevant as the "what" (attention monitoring) for cognitive performance.

Contrary to expectations, we did not find dispositional mindfulness to be associated with executive vigilance. Although speculative, differences in task demands between the ANTI-Vea and other assessments used in previous research may account for this null result. The high cognitive demand that characterizes the ANTI-Vea as a triple task sets it apart from other classic executive vigilance assessments, in which participants are required to perform a single task (e.g., CPT, SART). As simpler, less demanding tasks lead to less motivation and engagement, they are also more prone to mind-wandering, which is likely one important factor driving poor vigilance performance in this type of assessment. In turn, since dispositional mindfulness is known to be linked to diminished mind-wandering (Mrazek et al., 2012; see also our own secondary results), it may be argued that more mindful individuals perform better in simple vigilance tasks due to their reduced tendency to mind-wander. However, the ANTI-Vea being relatively more demanding, it may leave fewer cognitive resources available for participants to engage in mind-wandering. If this is true, the aforementioned advantage of more mindful individuals would be undermined in the context of our task, in which there is relatively little mind-wandering to be downregulated. As discussed below, future research manipulating task cognitive load and measuring actual on-task mind-wandering (e.g., via thought probes) while assessing the relationship between dispositional mindfulness and vigilance may prove useful in testing the validity of this explanation.

Also against our hypotheses, we did not find dispositional mindfulness to correlate with executive control. The abovementioned explanation for the lack of correlation with executive vigilance is also applicable here. Assuming that improvements in executive attention related to high mindfulness are due to better control over mind-wandering—as suggested by our secondary results—we may not have observed the expected correlation with executive control because mind-wandering was already reduced for all participants. In line with this interpretation, it has been observed that the interference effect of the executive control network is smaller in the ANTI-Vea as compared to other simpler flanker tasks (Luna, Barttfeld, et al., 2020; Luna, Telga, et al., 2020), a reduction that is hypothesized to be a consequence of the relatively high demands and low mind-wandering that characterize our task. In fact, the interference effect in the classic ANT is approximately twice as large as it is in the ANTI-Vea (usually ~ 100 ms and ~ 45 ms, respectively). As previously mentioned and discussed in more detail below, future research may find fruitful to include state (as opposed to trait) measures of mind-wandering, as well as retrospective reports of effort/fatigue, to further inquire whether or not and to what extent these factors are affecting the interference effect and, thus, the magnitude of its relationship to dispositional mindfulness.

A second plausible interpretation for the null result regarding executive control has to do with reliability and statistical power rather than with task characteristics. Note that while the ANTI-Vea measures for which we did observe statistically significant correlations demonstrated excellent reliability (raging from $r_{SB} = 0.91$ to $r_{SB} = 0.99$), the internal consistency of the executive control indices was not as high (ranging from $r_{SB} = 0.51$ to $r_{SB} = 0.64$). This has two consequences. On the one hand, it lends confidence to our correlational results regarding global attentional and arousal vigilance performance, further suggesting that they are indeed true positives and that their observed magnitude is not strongly attenuated by suboptimal measurement reliability (Dang et al., 2020). On the other hand, it means that our a priori power calculation underestimated the sample needed to detect correlations involving the attentional networks, including executive control.

Consider as an example the FFMQ total score ($\omega = 0.86$) and the executive control RT efficiency score ($r_{SB} = 0.64$). In order to detect a two-tailed correlation of $r = 0.20$ between them, the actual effect size one should aim for when estimating the sample size is $r = .20 * \sqrt{.86 * .64} = 0.15$. (see Dang et al., 2020). In this scenario, the sample needed to achieve the standard power of 0.80 would be of 346 participants, which stands in stark contrast to the 193 participants required in case of ideal reliability. By this logic, the observed null correlations involving the executive control indices might simply reflect type II errors. In fact, the same holds true for all other attentional networks efficiency measures, which showed similar or lower reliability. In contrast, and importantly, this also implies that positive findings from previous (smaller) studies correlating dispositional mindfulness and attentional networks tasks may indeed be type I errors (note that phasic alertness, orienting, and executive control outcomes in the ANTI-Vea are at least as reliable as those from previous ANT-related tasks; Luna et al., 2021). Considering all this, it is possible that the existing body of research assessing this relationship—our own study included—has been unable to address the phenomenon reliably. Future studies must consider factoring measurement reliability into their power calculations, and thus testing larger samples, in order to better gain access to it.

A subsidiary aim of our study was to explore the relationships between FFMQ and two subjective attention-related measures: the ACS and the MW-D/MW-S scales. Our results showed that participants with higher dispositional mindfulness (as assessed by the total FFMQ score) also reported having better attentional control and less spontaneous (but not voluntary) mind-wandering during daily life. This result is consistent with what can be theoretically expected: the higher the level of dispositional mindfulness, the larger the metacognitive capacity to voluntarily regulate attention in the presence of both external and internal distraction (as assessed by the ACS and MW-S, respectively). In turn, dispositional mindfulness was not related to deliberate mind-wandering (MW-D), arguably because this process reflects aspects that are both correlated and anticorrelated to mindfulness. For instance, while it is voluntary (reflecting, therefore, a metacognitive regulatory capacity possibly linked to mindfulness), it also entails the detachment from immediate sensory experience (thus opposing the construct of mindfulness).

Discussing the associations between these constructs and specific mindfulness facets is beyond the scope of the present report. Nonetheless, there is a rather wider observation that may be worth calling attention to, namely that the size of the correlations between FFMQ and objective ANTI-Vea measures is on average about half the size of the correlations between FFMQ and subjective self-report scores. This seeming discrepancy is not atypical when correlating measures addressing distinct levels of analysis of the same construct. For instance, Bernoster et al. (2019) addressed impulsivity (and other closely related constructs) simultaneously by using various self-report, behavioral, and electrophysiological measures. Similar to what we found, the authors observed that the measures were highly correlated within but not between each type of measurement (i.e., among self-report measures, but not between self-report and behavioral/electrophysiological measures), an observation for which they could not find a convincing explanation. Although speculative, one possibility is that such discrepancy is reflecting systematic noise derived from the subjective nature of self-report assessments.

Consider as an example attentional control. If a participant believes she has high attentional control, she will likely score also relatively high in at least some aspects of mindfulness (e.g., acting with awareness subscale) and low in (spontaneous) mind-wandering, independently of whether her belief is true or not. In contrast, this participant would only score relatively high in the executive attention index of the ANTI-Vea if her belief is indeed true. In other words, self-report assessments may not only measure the actual capacities or tendencies of the participants but also their subjective beliefs about them (for a similar argument, see Quigley et al., 2017). If we assume that individuals will have similar beliefs about related constructs, a systematic bias may be introduced so that correlations between overlapping self-report measures could be artefactually enlarged—while the observed shared variance between cognitive-behavioral and self-report data will more closely reflect the underlying relationship of interest. This is one example of the so-called common method bias, or the biasing effect that can be introduced when assessing the relationship between several constructs that have been measured using the same method (for a review, see Podsakoff et al., 2012). Although this explanation remains speculative, it highlights the value of using objective cognitive-behavioral measures, in addition to self-reports, to assess attention when studying its relationship to mindfulness and meditation practice.

Limitations and Future Research

The present study is not without limitations. First, our sample was composed of young, healthy participants with no meditation experience. This methodological feature precludes the generalization of our results beyond this population. Second, the relatively low reliability of some of our measures (especially those related to the attentional networks) hindered their capacity to detect small correlations, thus potentially increasing the probability of type II errors. And third, our subsidiary correlational results linking dispositional mindfulness, mind-wandering, and attentional control were obtained entirely from self-report measures, and may have therefore suffered from common method bias. In light of this, future research should consider (1) extending our results both to the general population and to other specific populations (such as, and especially, experienced meditators); (2) when feasible, testing even larger samples to buffer the reduction in statistical power derived from suboptimal measurement reliability; and, (3) relying on multiple, distinct measurement methods (e.g., self-report, cognitive-behavioral, thought probing, neurophysiology) so as to more validly assess the relationship between dispositional mindfulness, mind-wandering, and attention.

As mentioned above, future studies may also consider assessing the relationship between dispositional mindfulness and vigilance while manipulating cognitive load (i.e., the task demand). The online ANTI-Vea website affords the configuration of task demand by choosing whether to present a single, double, or triple task, thus being an accessible and convenient tool for researchers aiming to further explore this topic. It is also worth mentioning that our investigation included only trait measures of mind-wandering (MW-D and MW-S), which precludes drawing solid conclusions about the actual prevalence of mind-wandering during the task and its potential role mediating the relationship (or lack thereof) between dispositional mindfulness and executive attention performance. Future studies will thus benefit from including on-task measures of state mind-wandering (such as thought probes or retrospective reports) to better understand the relationships among these constructs in the context of the ANTI-Vea and similar tasks.

Given that our investigation entails the first attempt to research individual differences in trait mindfulness in relation to attention and vigilance performance by using the ANTI-Vea task, future studies replicating our findings are warranted. This may be particularly relevant for the correlations between Nonreact and the global attentional indices which, while robust when applying the preplanned contrasts, did not emerge using bidirectional comparisons. In addition, future similar research may also consider exploring alternative analytic approaches to the one reported herein. In particular, growth curve modeling may be a valuable alternative to address performance change over time (i.e., vigilance decrement), thus proving beneficial to further scrutiny the phenomena under investigation (McNeish & Matta, 2018). Finally, considering that we found non-reactivity to inner experience to be the facet most predictive of performance, future research may find it fruitful to deepen into the relationship between attention and vigilance and measures tapping into constructs related to non-reactivity, such as equanimity (Juneau et al., 2020) or non-attachment (Sahdra et al., 2010), to extend the findings reported herein.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12671-022-01850-6.

Acknowledgements The authors wish to thank Tao Coll-Martín, Fernando G. Luna, and Miguel A. Vadillo for the kind and helpful input provided during the development of this research project.

Author Contribution LC: conceptualization, methodology, investigation, data curation, formal analysis, visualization, writing – original draft; AC: methodology, writing – review and editing; JL: conceptualization, methodology, funding acquisition, writing – review and editing.

Funding Funding for open access charge: Universidad de Granada / CBUA. LC was supported by a doctoral fellowship from "la Caixa" Foundation (ID 100010434; fellowship code LCF/BQ/DE18/11670002). AC was supported by CIBEROBN, an initiative of the ISCIII (ISC III CB06 03/0052) and Ministerio de Economía y Competitividad (Spain) under AMABLE-VR (RTI2018-097835-A-I00). JL was supported by a research projects grant from the Spanish Agencia Estatal de Investigación, Ministerio de Economía y Competitividad (PSI2017-84926-P; PID2020-114790 GB-I00). This paper is part of the doctoral dissertation of the first author under the supervision of the last author.

Data Availability The data and R scripts used for analysis are provided at the Open Science Framework (https://osf.io/374rs/). The online version of the ANTI-Vea task is available for free use and in multiple languages at https://www.ugr.es/~neurocog/ANTI/.

Declarations

Ethical Approval The study was performed according to the ethical standards of the 1964 Declaration of Helsinki and its later amendments, and was part of a larger research project (PSI2017-84926-P) approved by the Universidad de Granada Ethical Committee (516/CEIH/2018).

Conflict of Interest The authors declare no competing interests.

Informed Consent All participants provided informed consent.

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