



# Attentional networks, vigilance, and distraction as a function of attention-deficit/hyperactivity disorder symptoms in an adult community sample

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Attentional difficulties are a core axis in attention-deficit/hyperactivity disorder (ADHD). However, establishing a consistent and detailed pattern of these neurocognitive alterations has not been an easy endeavour. Based on a dimensional approach to ADHD, the present study aims at comprehensively characterizing three key attentional domains: the three attentional networks (alerting, orienting, and executive attention), two components of vigilance (executive and arousal vigilance), and distraction. To do so, we modified a single, fine-grained task (the ANTI-Vea) by adding irrelevant distractors. One hundred and twenty undergraduates completed three self-reports of ADHD symptoms in childhood and adulthood and performed the ANTI-Vea. Despite the low reliability of some ANTI-Vea indexes, the task worked successfully. While ADHD symptoms in childhood were related to alerting network and arousal vigilance, symptoms in adulthood were linked to executive vigilance. No association between ADHD symptom severity and executive attention and distraction was found. In general, our hypotheses about the relationships between ADHD symptoms and attentional processes were partially supported. We discuss our findings according to ADHD theories and attention measurement.

Attentional difficulties are one of the core axes in attention-deficit/hyperactivity disorder (ADHD). However, establishing a consistent and detailed pattern of these alterations at the neurocognitive level has not been an easy endeavour, with rather inconsistent and null findings (Huang-Pollock & Nigg, 2003; Huang-Pollock, Nigg, & Carr, 2005; Wilding, 2005). In the development of translational science, identifying such neurocognitive mechanisms underlying ADHD symptoms is crucial to enhance the approach to the disorder (Castellanos & Tannock, 2002; Luo, Weibman, Halperin, & Li, 2019; Sonuga-Barke & Halperin, 2010). Moreover, recent advances towards a dimensional model of ADHD have led to an interest in studying the neurocognitive correlates of ADHD symptoms in non-clinical community samples (Hilger & Fiebach, 2019; Hilger et al., 2020). Before

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introducing this dimensional framework underpinning the present study, we will describe the literature on attentional functioning in ADHD, which is mostly built upon case–control designs.

Neurocognitive research on attention in ADHD should be grounded on theoretical frameworks that consider the distinct aspects of attention along with their neurobiological substrates (Booth, Carlson, & Tucker, 2007; Bush, 2010). Different theories have emphasized different aspects of attention, giving rise to a diversity of attentional phenomena that have even led some authors to question the very existence of attention as a consistent phenomenon (Hommel et al., 2019). Alternatively, the three attentional networks model by Posner and colleagues (Petersen & Posner, 2012; Posner & Petersen, 1990) tries to solve this problem by considering the attentional system as three independent, albeit interactive, networks, each one implementing a different attentional function. First, the *alerting network* regulates the level of arousal and activation for both momentary readiness to imminent events (phasic alertness) and sustained performance over long time periods (tonic alertness or vigilance). This network involves noradrenergic innervations from the locus coeruleus towards frontal and parietal lobes of the right hemisphere. The second subsystem is the *orienting network*, responsible for prioritizing sensory inputs by selecting a modality or spatial location or object. It comprises cortical regions such as parietal cortices and frontal eye fields, and the subcortical structures of pulvinar nuclei and superior colliculi. Finally, the *executive network* is in charge of monitoring performance and prioritizing goal-oriented responses in conflict situations. This third subsystem includes the anterior cingulate and prefrontal regions.

Several tasks have been developed to simultaneously measure these three components of attention, the most common being the Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002; see de Souza, Faria, & Klein, 2021, for a review). This computerized task and other variants like the ANTI (Attention Network Test for the interaction; Callejas, Lupiáñez, & Tudela, 2004) presents a sequence of visual stimuli that combines a spatial cueing (Posner, 1980) and warning signal task with a flanker paradigm (Eriksen & Eriksen, 1974). Subtractions between the tasks conditions resulting from specific manipulations of warning, cueing, and flankers provide the effects of *alerting*, *orienting*, and *congruency* (an index of the executive network), respectively. Different from the ANT, the use of a different cue for measuring alertness and orienting in the ANTI also allows the measure of the interaction between the three attentional networks.

Extensive research has used the ANT/ANTI or some of its variants to analyse the attentional networks in ADHD. A recent meta-analysis including the ANT and the ANT child version (Rueda et al., 2004) compared 491 ADHD children with 402 typical developing controls in nine studies (Arora, Lawrence, & Klein, 2020). They found the functioning of the alerting and executive networks – but not orienting – to be impaired in ADHD. Moreover, Mullane, Corkum, Klein, McLaughlin, and Lawrence (2011) reported similar group differences using the ANTI. These results support Berger and Posner's (2000) original predictions regarding attentional networks in ADHD. In the same vein, impaired alerting and executive processes fall in line with energetic (Sergeant, 2000, 2005) and executive (Barkley, 1997) accounts of ADHD (Martella, Aldunate, Fuentes, & Sánchez-Pérez, 2020), respectively.

Notwithstanding the numerous studies using the ANT as a tool to characterize the attentional profile of ADHD, some concerns with this literature motivated our work. First, compared to children, the amount of research on ADHD adults and the ANT is somewhat limited (Vázquez-Marrufo, García-Valdecasas Colell, Galvao-Carmona, Sarrias-Arrabal, & Tirapu-Ustároz, 2019). Moreover, this body of research offers mixed evidence about

ADHD deficits in alerting and executive networks (Bueno et al., 2015; Hasler et al., 2016; Lampe et al., 2007; Oberlin, Alford, & Marrocco, 2005), with those studies of greater statistical power failing to find differences between ADHD and controls individuals (Lundervold et al., 2011). Thus, the functioning of the attentional networks in relation to adult ADHD symptomatology remains unclear. The two remaining issues concern the role of *vigilance* and *distraction* in the ANT/ANTI as well as in the literature of attentional processes in ADHD. The next two sections will address each of them.

### **Measuring vigilance in ADHD: a novel ANT version**

Vigilance, understood as the attentional capacity to maintain performance over time, is one of the most widely studied phenomena in the ADHD literature (Huang-Pollock, Karalunas, Tam, & Moore, 2012; Schoechlin & Engel, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). The variety of terms and measures linked to vigilance have led some researchers to deem it as a multicomponent concept (Langner & Eickhoff, 2013; Luna, Marino, Roca, & Lupiáñez, 2018; Sturm et al., 1999).

On the one hand, vigilance tasks often consist in detecting an infrequent target among non-target stimuli (e.g., Test of Variables of Attention [TOVA], Greenberg & Waldman, 1993), in line with the Continuous Performance Test (CPT) paradigm, suggesting executive aspects of vigilance (Luna et al., 2018). Substantial research has shown that both ADHD children (Huang-Pollock et al., 2012, 2020) and adults (Advokat, Martino, Hill, & Gouvier, 2007; Barkley & Murphy, 2011; Nikolas, Marshall, & Hoelzle, 2019; Riccio & Reynolds, 2006; Salomone, Fleming, Bramham, O'Connell, & Robertson, 2020) exhibit worse performance in numerous CPT indexes (i.e., reaction time [RT] mean and variability, hits, false alarms, and  $d'$ ). However, most of these studies only compare overall performance, rather than vigilance decrement over time (i.e., group-by-time interaction), the defining feature of vigilance (Esterman & Rothlein, 2019; Huang-Pollock et al., 2012; Tucha et al., 2017). Indeed, research examining such change over time has often failed to demonstrate a greater vigilance decline in ADHD individuals (Cohen & Shapiro, 2007; Epstein, Conners, Sitarenios, & Erhardt, 1998; Epstein, Johnson, Varia, & Conners, 2001; Johnson et al., 2001; Solanto, Etefia, & Marks, 2004; Tucha et al., 2009). Only a few studies found that, compared to controls, ADHD participants displayed over time higher variability (Marchetta, Hurks, De Sonnevill, Krabbendam, & Jolles, 2008; Weyandt, Oster, Gudmundsdóttir, DuPaul, & Anastopoulos, 2017), more false alarms (Tucha et al., 2017), and lower reaction time (Weyandt et al., 2017) or fewer hits (Gmehlin et al., 2016).

Alternatively, vigilance has been operationalized as reactivity to the environment, reflecting tonic arousal levels (Luna et al., 2018; Oken, Salinsky, & Elsas, 2006), and measured with tasks demanding fast reactions to stimuli without exerting much control (i.e., without response selection; e.g., the Psychomotor Vigilance Test, Dinges & Powell, 1985). When these tasks are extremely short ( $\leq 20$  trials), no differences between ADHD and controls have been found (Tucha et al., 2006, 2008, 2009). Nonetheless, as tasks are longer, some evidence indicates that both children and adults with ADHD show slower RT and higher variability of response (Mary et al., 2016; Tucha et al., 2017). Similar to CPT, only a few studies have measured performance over time for this type of vigilance, with ADHD adults exhibiting a greater increase in variability – in terms of standard deviation or lapses, but not in mean RT (Gmehlin et al., 2016; Tucha et al., 2017).

Although some efforts have been made to obtain measures of vigilance from the ANT/ANTI in the ADHD literature (Adólfssdóttir, Sørensen, & Lundervold, 2008; Bueno et al., 2015; Lundervold et al., 2011), these tasks cannot provide a direct measure of such

construct (Roca, Castro, López-Ramón, & Lupiáñez, 2011). A novel version of the ANT has been developed: the *ANT for Interactions and Vigilance – executive and arousal components* (ANTI-Vea; Luna et al., 2018). Grounded on the aforementioned distinction, the ANTI-Vea is suitable to measure the two independent aspects of vigilance besides the three attentional networks and their interactions. To assess *executive vigilance* (EV), the flanker task is embedded in a CPT structure where participants have to detect a rare target. For its part, *arousal vigilance* (AV) is measured with a salient stimulus (i.e., a red down counter) that participant must stop as fast as possible. Worthy of note, the length of the task (~33 min) enables the analysis of the decrement of both types of vigilance across the six blocks with sufficient precision and adequate reliability for using the task in experimental designs (Luna, Roca, Martín-Arévalo, & Lupiáñez, 2020).

Research on the ANTI-Vea has focused on providing empirical dissociation of and task sensitivity to both vigilance components. In this vein, EV decrement – but not AV – is mitigated by high-definition transcranial direct current stimulation over the right frontal and parietal cortices (Luna, Román-Caballero, Román-Caballero, Barttfeld, Lupiáñez, & Martín-Arévalo, 2020) or acute moderate exercise (Sanchís, Blasco, Luna, & Lupiáñez, 2020) and modulated by the cognitive task load (Luna, 2019). Conversely, AV decrement – but not EV – is reduced by acute caffeine intake (Sanchís et al., 2020) and increased with fatigue across 8 hr of testing (Feltmate, Hurst, & Klein, 2020). Furthermore, the ANTI-Vea has been used to study individual differences related to musical (Román-Caballero, Martín-Arévalo, & Lupiáñez, 2021) or sport (Huertas et al., 2019) practice as well as mindfulness and mind-wandering dispositions (Cásedas, Cebolla, & Lupiáñez, 2021). No previous studies have employed this task in the field of ADHD.

### **Measuring distraction in ADHD: a novel paradigm**

Although distraction is central to ADHD symptomatology, evidence of increased distractor interference in ADHD is rather inconsistent (Albrecht et al., 2008; Brodeur & Pond, 2001; Chan et al., 2009; Huang-Pollock et al., 2005; Lundervold et al., 2011; Mason, Humphreys, & Kent, 2004; Wilding, 2005). Forster (2013) pointed out that this literature failed in the attempt to employ a paradigm with distractors that were entirely irrelevant to the task. For instance, in the response-competition paradigm (e.g., flanker tasks), although distractors appear in an irrelevant location where the target is never presented, their identity is highly relevant to the task, as it is associated with one of the target responses (i.e., congruent vs. incongruent). This does not reflect the type of distraction that interferes with people – mostly those with ADHD – in daily life, where the distractor (e.g., a mobile notification) is entirely unrelated to the task being performed (e.g., reading a paper).

Therefore, to measure task-irrelevant distraction, distractors must be presented in an irrelevant location, unrelated to any task responses, visually dissimilar from the search stimuli, and irrelevant to any attentional setting for the current task (Forster, 2013). In line with this, Forster and Lavie (2008) designed the *irrelevant-distractor paradigm* to measure the interference associated with the peripheral presentation of a colourful salient task-irrelevant distractor, typically a well-known character (e.g., Pikachu). Using this paradigm, ADHD adults exhibited higher irrelevant distraction than controls (Forster, Robertson, Jennings, Asherson, & Lavie, 2014). Crucially, Forster and Lavie (2016) found that while interference from irrelevant distractors correlated positively with ADHD symptoms in non-clinical adults, interference from response-competition distractors did not.

Since the ANTI-Vea measures interference by a response-competition paradigm (i.e., flanker task), it may be possible that integrating the irrelevant-distractor paradigm could enhance the task sensitivity to ADHD symptoms.

### ***A dimensional model of ADHD***

Classical disease models and diagnostic systems have conceptualized mental disorders as discrete categories qualitatively different from normality. Nevertheless, converging evidence at behavioural (Haslam et al., 2006), neurocognitive (Frazier, Youngstrom, & Naugle, 2007), and genetic (Gjone, Stevenson, & Sundet, 1996) levels supports a *dimensional* rather than a categorical structure of ADHD. A dimensional model posits continuity in symptoms and underlying causes, so that ADHD would be viewed as an extreme expression of normal variation in the population (Coghill & Sonuga-Barke, 2012; Sonuga-Barke, 2013). This approach opens up new opportunities to ADHD-related research.

On the one hand, neurocognitive ADHD theories could serve to explain symptom-level variation in non-clinical or community samples (Hilger & Fiebach, 2019; Hilger et al., 2020). Conversely, research on neurocognitive correlates of ADHD symptom severity in community samples might shed light on processes likely to be altered in ADHD (Coghill & Sonuga-Barke, 2012). For example, impaired vigilance (Craig & Klein, 2019) and higher irrelevant distraction (Forster & Lavie, 2016) positively correlated with ADHD symptoms in non-clinical samples (but see Craig & Klein, 2019, and Zamani Sani et al., 2020, for null findings on attentional networks). However, unless a substantial number of individuals with ADHD are included in community samples, these correlational designs might only offer preliminary or indirect insights about the disorder, which need to be confirmed in clinically referred samples. Worthy of mention, even subclinical variations in ADHD symptoms have been associated with negative family impact, psychosocial problems, and poorer satisfaction with life (Cussen, Sciberras, Ukoumunne, & Efron, 2012; Gudjonsson, Sigurdsson, Eyjolfsson, Smari, & Young, 2009).

### ***The present study***

The aim of our study was to investigate the main attentional processes related to ADHD symptoms through a single, fine-grained task. For that purpose, we integrated the irrelevant-distractor paradigm into the ANTI-Vea. This allows simultaneous measures of the attentional networks, vigilance, and distraction, three key domains in the field of attention and ADHD. To characterize ADHD symptoms, we employed a community sample of undergraduates, and both childhood and current symptoms were evaluated. Grounded on the aforementioned literature, we expected higher ADHD symptoms to predict (a) poorer functioning in alerting and executive networks (i.e., higher effects), but not in orienting; (2) impoverished EV and AV – crucially in performance over time (i.e., vigilance decrement); and (3) a higher irrelevant-distraction effect.

## **Method**

### ***Participants***

Following the reference work by Forster and Lavie (2016), we decided to collect data from 120 participants. This sample size allows the detection of a small to medium effect size ( $r = .22$ ; smaller than  $r = .32$ , observed by Forster & Lavie, 2016) in one-tailed, zero-order

correlations with  $1 - \beta = .80$  and  $\alpha = .05$ , as computed with G\*Power 3.1. Therefore, a sample of 120 undergraduates from a Spanish university participated in the study. They received extra credit course as a compensation for their voluntary participation. All participants (97 women, 23 men; age,  $M = 20.21$ ,  $SD = 1.91$ , range 18–28) were Spanish-speaking and had a normal or corrected-to-normal vision. Two participants reported a prior diagnosis of ADHD. All participants completed an informed consent form. The study was conducted in accordance with the guidelines laid down by our institutional ethics committee, in compliance with the ethical standards of the 1964 Declaration of Helsinki, and was part of a larger research project approved by our institutional ethics committee.

### **Instruments**

#### *Barkley Adult ADHD Rating Scale-IV: childhood and current symptoms*

The self-reports of the Barkley Adult ADHD Rating Scale-IV (BAARS-IV; Barkley, 2011) include two scales to assess ADHD symptoms: retrospectively in childhood (cBAARS-IV) and concurrently in adulthood (aBAARS-IV). Each scale is composed of 18 items, nine of inattention (e.g., ‘forgetful in daily activities’) and nine of hyperactivity–impulsivity (e.g., ‘fidget with hands or feet or squirm in seat’), in a Likert scale ranged from 1 (*never or rarely*) to 4 (*very often*). Since the items are based on the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; DSM-IV; American Psychiatric Association [APA], 1994), we used the Spanish version of the manual for the translation (APA, 1994/1995). In our sample, reliability was  $\alpha = .89$  and  $\alpha = .86$  for cBAARS-IV and aBAARS-IV, respectively, close to the  $\alpha = .95$  and  $\alpha = .92$  of the original BAARS-IV (Barkley, 2011). Barkley proposed the 95th percentile as a cut-off to identify individuals at high risk of ADHD.

#### *Adult ADHD Self-Report Screening Scale for DSM-5*

The Adult ADHD Self-Report Screening Scale for DSM-5 (ASRS-5; Ustun et al., 2017) specifically assesses the adult presentation of ADHD based on DSM-5 conceptualization (APA, 2013). It includes six items (e.g., ‘how often do you put things off until the last minute’) in a 5-point Likert scale (0 = *never* to 4 = *very often*). Items 1–4 had been adapted into Spanish from a previous versions of the ASRS (Sanchez-Garcia et al., 2015). For items 5 and 6, we used the forward translation of the ASRS-5 from a Spanish journal specialized in health sciences (Redacción Médica, n.d.). Then, both items were back-translated into English, where no discrepancies were found. Reliability of ASRS-5 in our sample was  $\alpha = .64$ , which is within the range of the original study (Ustun et al., 2017), in which a threshold of 14 points was established as preferred for screening purposes.

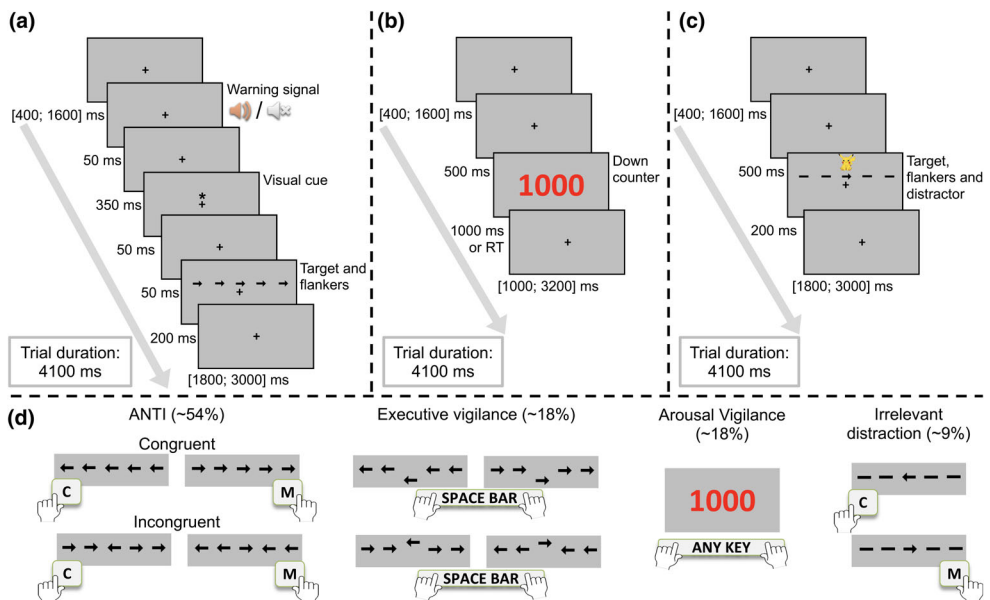
#### *ANTI-Vea with irrelevant distractors*

The original ANTI-Vea (Luna et al., 2018; see online version on <https://www.ugr.es/~neurocog/ANTI/>), which evaluates the three attentional networks (ANTI trials) and two types of vigilance (EV and AV trials), was modified in order to add the irrelevant-distractor paradigm on the task (ID trials). Everything was used as in the original task, except that 8 ID trials were added to each of the 6 blocks of trials. These trials were built as ANTI trials (see below), but with the replacement of non-target arrows by lines, and the inclusion of a completely irrelevant distractor.

## Procedure

The study was conducted between November 2019 and March 2020 – before COVID-19 preventive measures were implemented in our region. First, participants filled out an online survey – via LimeSurvey (<https://www.limesurvey.org>) – composed of questionnaires about attention and distraction dispositions.<sup>1</sup> The survey began with the cBAARS-IV, the aBAARS-IV, and the ASRS-5, in that order, and ended with a question about previous diagnosis of ADHD. After completing the survey, participants were invited in our laboratory to conduct the cognitive task.

Upon arrival at the laboratory, participants were individually brought into a soundproof room adequately illuminated. Participants were sitting at about 60 cm from a 15-inch computer screen with an aspect ratio of 16:9. Participants were provided with headphones at 60% sound level of the computer and were asked to turn-off or silence their mobile phone. Then, the experimenter presented the ANTI-Vea, designed and run in E-Prime (Version 2.0; Psychology Software Tools & Inc., 2012). The stimuli sequence and correct responses for each type of trial are depicted in Figure 1.



**Figure 1.** Attention Network Test for Interaction and Vigilance – Executive and Arousal components (ANTI-Vea) procedure in our study. Note. Panel A: Temporal sequence in Attention Network Test for Interaction (ANTI) and Executive Vigilance (EV) trials. Target and flankers could appear above (see example) or below the fixation point. Visual cue could appear in the same location as the target (valid cue; see example), in the opposite location (invalid cue), or could not appear (no cue). Panel B: Temporal sequence in Arousal Vigilance (AV) trials. Panel C: Temporal sequence in Irrelevant distraction (ID) trials. Target and flankers could appear above (see example) or below the fixation point. Irrelevant distractor could appear at the top (see example) or at the bottom of the screen; or it could not appear. Distractor could be Pikachu (see example), SpongeBob, or Mickey Mouse. Panel D: Correct responses for each type of trial. The five arrows are randomly displaced  $\pm 2$  px to generate noise in ANTI and ID trials, and the target is displaced by 8 px in EV trials.

<sup>1</sup> The full set of questionnaires, which is part of a larger project, is available at a public repository (<https://osf.io/k8jdm/>).

All the trials lasted 4,100 ms and had a fixation point constantly present at the centre of the screen. The ANTI-Vea comprised four different types of trials: the three from the original task (ANTI, EV, and AV) and one added to measure irrelevant distraction (ID). Trials were pseudorandomly presented within their experimental block. In ANTI (~54%; 48 trials per block) and EV trials (~18%; 16 trials per block), an auditory warning signal sounded in half of the trials (*tone condition*), whereas in the other half, no warning signal was presented (*no-tone condition*). Next, an asterisk (i.e., visual spatial cue) appeared in two third of the trials, equally presented in the same (*valid condition*) or the opposite (*invalid condition*) location as the upcoming target. A central arrow (i.e., target) with four flankers appeared 100 ms later either above or below the fixation point. In ANTI trials, participants had to discriminate the direction of the target (by pressing either 'c' for leftward direction or 'm' for rightward direction) while ignoring the direction of the flanking arrows, which could equally point to the same (*congruent condition*) or the opposite (*incongruent condition*) as the target. In contrast, on EV trials the target appeared vertically displaced for participants to detect the displacement by pressing the space bar. In contrast, AV trials (~18%; 16 trials per block) only displayed a red millisecond down counter at a variable time interval (900–2,100 ms) for participants to stop it by pressing any key as fast as possible. Finally, ID trials (~9%; 8 trials per block) had the same structure and correct response as ANTI trials without tone or cue, except (1) non-target arrows were replaced by lines to reduce perceptual load and (2) in half of the trials, an irrelevant distractor (SpongeBob, Pikachu, or Mickey Mouse; ~200 px width × ~200 px height) appeared either at the top or at the bottom of the screen (above ~150 px- or below ~290 px- the central arrow) for the same time as the target (*distractor present condition*), whereas no distractor was presented in the other half (*distractor absent condition*).

The ANTI-Vea task started with several phases of progressive practice, as in Luna et al. (2018), with the addition of 8 ID trials in a last practice block of 48 randomized trials (24 ANTI, 8 EV, 8 AV, and 8 ID) without visual feedback. Before this practice block, the three type of distractors were shown to participants, who were told to 'ignore them for being irrelevant to the task goal'. After this block, participants were given the possibility to search for and ask any questions to the experimenter, who had left the room at the beginning of the practice phase. Then, participants started the six seamless experimental blocks (48 ANTI, 16 EV, 16 AV, 8 ID trials per block). The whole experimental session – instructions and task – lasted ~50 min.

### Data analysis

Behavioural data were treated based on Luna et al. (2018) through an R script. Because of a computer or experimenter error, ANTI-Vea data from three participants were corrupted and they could not be analysed. Participants with more than 25% errors in ANTI trials ( $n = 4$ , among them, one of the two participants with ADHD) were excluded from all task analyses, and those remaining participants with more than 25% errors in the distractor present condition ( $n = 11$ ) were excluded from all ID trials analyses.<sup>2</sup> For ANTI and ID RT analyses, trials with incorrect responses (ANTI = 5.75%; ID = 5.68%) and RTs smaller than 200 ms (ANTI = 1.24%; ID = 1.96%) or higher than 1,500 ms (ANTI = 0.45%; ID = 0.78%) were excluded.

<sup>2</sup> This filter for (ID) trials was added in response to the first data analysis, due to the extremely high percentage errors of these participants in the distractor present condition ( $Mdn = 0.94$ ). Most of them probably understood that 'ignore the distractors' meant 'do not response when the distractor appears'.



We extracted several measures from the ANTI-Vea. For *mean RT* and *percentage errors* in ANTI trials, we calculated the *overall mean score* and difference scores for *alerting* (no-tone–tone conditions<sup>3</sup>), *orienting* (invalid–valid conditions), and *congruency* (incongruent–congruent conditions). Following Luna, Barttfeld, Martín-Arévalo, and Lupiáñez (2021), EV outcomes included *hits* (percentage of correct responses in EV trials), *false alarms* (percentage of space bar responses in ANTI trials with more than 2 px from the target to at least one of its two adjacent flankers), and the signal detection theory metrics of *A'* (sensitivity) and *B''* (response bias). AV outcomes compressed the *mean RT*, the *standard deviation RT*, and the *percentage of lapses* (RTs > 600 ms). Each EV and AV outcome included both the *overall performance* and the *slope* of the regression line – representing performance over the six experimental blocks. Finally, ID trials provided interference from irrelevant distractor. As per Forster and Lavie (2016), we computed the *percentage increase in mean RT* due to distraction by dividing the difference score (distraction present – distractor absent conditions) by RT in the distractor absent conditions. Distraction interference in *percentage errors* only employed raw difference scores.

We analysed the quality of the ANTI-Vea measures. First, we checked the task functioning. To this end, we conducted Student's *t*-tests for indexes based on difference scores. For indexes based on performance over experimental blocks (i.e., EV and AV slopes), we conducted six-level one-way repeated-measures analyses of variance (ANOVAs) with planned comparisons to test the polynomial linear component. Where appropriate, Huynh–Feldt or Greenhouse–Geisser corrections were applied. Second, we estimated the reliability of each ANTI-Vea outcome. To do so, we used a permutation-based split-half correlation approach with 10,000 random splits and then applied the Spearman–Brown correction (for a rationale, see Parsons, Kruijt, & Fox, 2019). These reliability estimations were computed by adapting an R script that had previously been used with the original ANTI-Vea (Luna, Roca, et al., 2020).

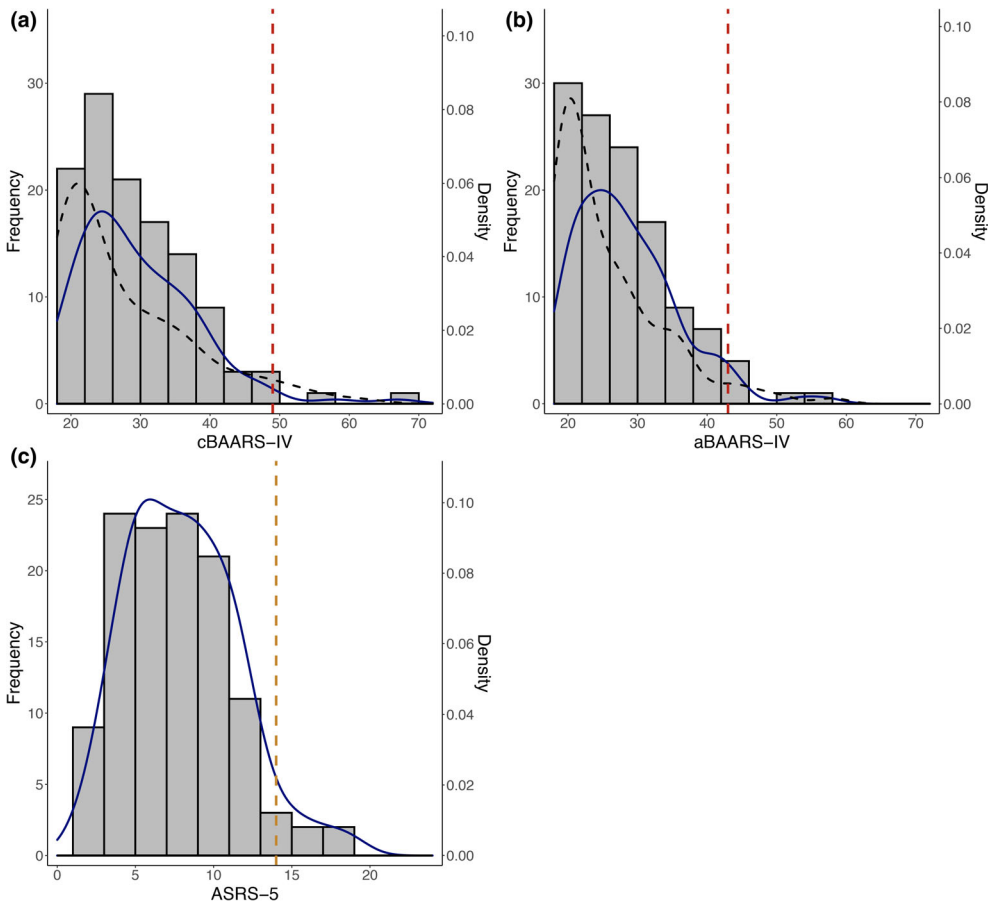
Finally, we used JASP (Version 0.13; JASP Team, 2020) to test the correlations between the three questionnaires of ADHD symptoms (i.e., cBAARS-IV, aBAARS-IV, and ASRS-5) and the 24 ANTI-Vea outcomes (8 ANTI, 8 EV, 6 AV, and 2 ID). Normality was violated for the vast majority of pairwise comparisons, as assessed by Shapiro–Wilk tests. Therefore, we used the Kendall's  $\tau$  rank correlation coefficient, interpreted as per Gilpin (1993): .07 = small, .21 = medium, .35 = large. We conducted one- or two-sided contrasts according to whether they were based on directional or non-directional hypotheses. Statistical significance was set at  $\alpha = .05$ .

## Results

### ADHD self-reports

Figure 2 shows the distribution of ADHD symptoms compared to an estimated normative sample (for a detailed procedure and statistical report, see Text S1). Taking together, although ADHD symptom distributions in our sample might slightly differ from the population, this does not seem to undermine its spread and variability throughout each scale, as compared to an estimated normative sample.

<sup>3</sup> Although the measure exclusively considering the no-cue conditions is a purer measure of alertness, the measure considering all conditions is more powerful and reliable (de Souza et al., 2021).



**Figure 2.** Distribution of total ADHD symptom scores for each of the three scales compared to an estimated normative sample. Note.  $N = 120$ . ADHD = Attention-deficit/hyperactivity disorder. Histogram and blue solid line represent the frequency and density curve of ADHD total scores in the study sample. Dashed black lines represent the density curve of ADHD total scores in an estimated normative sample. This normative, equally sized sample was obtained by extracting 120 quantiles from a large bootstrapped sample ( $N = 10,000$ ) that fits the percentile values available in Barkley (2011). Vertical dashed red lines represent the normative 95th percentile, a cut-off to identify individuals at high risk of ADHD. The vertical dashed orange line represents a threshold for ADHD screening purposes. Panel A: cBAARS-IV = Barkley Adult ADHD Rating Scale-IV: Childhood Symptoms. Panel B: aBAARS-IV = Barkley Adult ADHD Rating Scale-IV: Current Symptoms. Panel C: ASRS-5 = Adult ADHD Self-Report Screening Scale for DSM-5.

Unsurprisingly, the cBAARS-IV ( $M = 29.6$ ,  $SD = 8.46$ ), the aBAARS-IV ( $M = 28.4$ ,  $SD = 7.32$ ), and the ASRS-5 ( $M = 8.04$ ,  $SD = 3.54$ ) showed significant positive correlations among them, with effect sizes from medium to large. Concretely, for the cBAARS-IV with the aBAARS,  $r(118) = .51$ ,  $p < .001$ , for the cBAARS-IV with the ASRS-5,  $r(118) = .35$ ,  $p < .001$ , and for the aBAARS-IV with the ASRS-5,  $r(118) = .70$ ,  $p < .001$ . Interestingly, the correlation between the two measures of symptoms in adulthood was higher than those between these measures and the one of symptoms in childhood.

**ANTI-Vea**

Table 1 shows descriptive statistics, reliability, and correlations with ADHD symptoms for each of the ANTI-Vea indexes. Correlations among ANTI-Vea indexes are presented in Table S2.

**Table 1.** Descriptive statistics, reliability, and Kendall's rank correlations with ADHD symptoms in childhood and adulthood for all ANTI-Vea outcomes

ANTI-Vea index	M	SD	$r_{SB}$	Kendall's $\tau$ correlation coefficient		
				cBAARS-IV	aBAARS-IV	ASRS-5
<b>ANTI outcomes</b>						
RT overall	600	95	.99	.06	-.08	-.03
% errors overall	5.75	4.34	.91	.06	-.08	-.06
RT alerting	20	23	.47	.13*	.10	.03
% errors alerting	2.33	3.79	.51	.15*	.09	.05
RT orienting	35	26	.36	.01	.02	.11
% errors orienting	0.65	3.90	.26	.04	-.01	-.05
RT congruency	40	28	.66	.05	.03	.03
% errors congruency	1.46	4.21	.60	.03	.01	-.06
<b>EV outcomes</b>						
% hits	68.62	17.29	.94	.001	-.05	.01
% false alarms	5.16	5.09	.85	-.001	-.11	-.02
$A'$ (sensitivity)	0.90	0.04	.88	-.01	-.02	.02
$B''$ (response bias)	0.59	0.35	.86	-.02	.11	.02
% Hits slope	-1.74	3.00	.27	-.02	-.04	-.11*
% False alarms slope	-0.42	1.51	.40	.05	.09	.11*
$A'$ (sensitivity) slope	-0.003	0.01	.40	-.03	-.09	-.14*
$B''$ (response bias) slope	0.04	0.10	.26	-.01	-.11	-.08
<b>AV outcomes</b>						
RT mean	504	58	.97	.11*	.04	.10
RT standard deviation	97	49	.88	.11*	.06	.01
% lapses	12.98	14.35	.96	.11*	.07	.08
RT mean slope	5.36	12.47	.75	.17**	.06	-.01
RT SD slope	6.10	12.62	.54	.08	.02	-.05
% lapses slope	1.99	3.74	.78	.18**	.06	-.01
<b>ID outcomes<sup>a</sup></b>						
% interference in RT	5.37	7.35	.21	.02	.02	.03
% errors interference	0.61	6.49	.03	-.01	.02	.05

Note.  $n = 113$ . According to our hypotheses, correlation tests are one-tailed for positive correlations in all indexes, except (1) orienting (RT and errors; two-tailed); (2) hits and  $A'$  (both overall and slope; one-tailed for negative correlations); and (3)  $B''$  (only overall; two-tailed), as it is the only index not directionally associated with performance in vigilance.

aBAARS-IV = Barkley Adult ADHD Rating Scale-IV: Current Symptoms; ADHD = Attention-deficit/hyperactivity disorder; ANTI = Attention Network Test for Interaction; ASRS-5 = Adult ADHD Self-Report Screening Scale for DSM-5; AV = Arousal Vigilance; cBAARS-IV = Barkley Adult ADHD Rating Scale-IV: Childhood Symptoms; EV = Executive vigilance; ID = Irrelevant distraction;  $r_{SB}$  = Spearman-Brown reliability coefficient; RT = Reaction time.

<sup>a</sup> $n = 102$ ; \* $p < .05$ , one-tailed; \*\* $p < .01$ , one-tailed. No other  $p < .05$  appeared with exploratory two-tailed tests.

*ANTI outcomes*

As reported by Luna et al. (2018), ANTI trials revealed effects of alerting, orienting, and congruency for RTs and, except orienting ( $p < .077$ ), for percentage errors. Specifically, RTs were faster in the tone than in the no-tone trials,  $t(112) = -9.18, p < .001, d = -0.84$ , in valid than invalid trials,  $t(112) = -14.45, p < .001, d = -1.36$ , and in congruent than incongruent trials,  $t(112) = -14.80, p < .001, d = -1.39$ . Percentage errors were higher in no-tone than in tone trials,  $t(112) = 6.54, p < .001, d = 0.62$ , and in incongruent than congruent trials,  $t(112) = 3.69, p < .001, d = 0.35$ . Reliability of ANTI outcomes ranged from  $r_{SB} = .26$  to  $r_{SB} = .99$ , with the usual higher values for overall than for difference scores (see Table 1).

In line with our hypotheses, we observed significant positive correlations between the cBAARS-IV and the magnitude of the alerting effect (i.e., the difference between no-tone and tone trials) in both RTs,  $\tau(111) = .13, p = .021$ , and percentage errors,  $\tau(111) = .15, p = .013$ . Such correlations were not significant for the aBAARS-IV (both  $p > .063$ ) and the ASRS-5 (both  $p > .248$ ). Contrary to our predictions, none of the three ADHD symptom self-reports significantly correlated with the overall scores of RT (all  $p > .193$ ) or percentage errors (all  $p > .186$ ) nor with the congruency effect, either measured with RTs (all  $p > .205$ ) or percentage errors (all  $p > .314$ ). Finally, as expected, orienting indexes of RT (all but one  $p > .804$ ) and percentage errors (all  $p > .085$ ) did not correlate with any ADHD symptom self-report.

*EV outcomes*

The four EV indexes of overall performance (i.e., hits, false alarms,  $A'$ , and  $B''$ ) yielded high reliability scores, from  $r_{SB} = .85$  to  $r_{SB} = .94$  (see Table 1). However, none of these indexes showed significant correlations with any of the three ADHD symptom self-reports (all but one  $p > .077$ ).

Consistent with Luna et al. (2018), we found a main effect of experimental block for hits,  $F(5, 560) = 8.85, p < .001, \eta^2 = .07$ , false alarms,  $F(4.51, 505.16) = 2.56, p < .032, \eta^2 = .02$ , and  $B''$ ,  $F(4.79, 536.58) = 4.13, p < .001, \eta^2 = .04$ . Planned comparisons revealed a linear component indicating that, over the six blocks, there was a decrement in the percentage of hits,  $t(560) = -6.27, p < .001$ , and false alarms,  $t(112) = -2.94, p = .004$ , as well as an increase in  $B''$ ,  $t(112) = 4.01, p < .001$ . Different from Luna et al., we also observed the block effect on  $A'$ ,  $F(4.28, 478.82) = 2.91, p < .019, \eta^2 = .03$ , yielding a linear decrease over the blocks,  $t(112) = -3.13, p = .002$ . These indexes of slope exhibited a low reliability, ranging from  $r_{SB} = .26$  to  $r_{SB} = .40$ .

Concerning our hypotheses, only the ASRS-5 correlated with three indexes of EV slopes. Specifically, higher ASRS-5 scores predicted a greater decrement in percentage of hits,  $\tau(111) = -.11, p = .044$ , and  $A'$  (sensitivity),  $\tau(111) = -.14, p = .017$ , as well as a more attenuated decrement in percentage of false alarms,  $\tau(111) = -.11, p = .044$ . The remaining correlations were not significant (all  $p > .085$ ).

*AV outcomes*

Similar to EV, we found high reliability for the three AV indexes of overall performance, oscillating between  $r_{SB} = .88$  and  $r_{SB} = .97$  (see Table 1). As predicted, the cBAARS-IV exhibited significant positive correlations with the three indexes, namely mean RT,  $\tau(111) = .11, p = .043$ , standard deviation of the RT,  $\tau(111) = .11, p = .044$ , and percentage of

lapses,  $\tau(111) = .11$ ,  $p = .041$ . Neither the aBAARS-IV nor the ASRS-5 significantly correlated with any AV index (all  $p > .061$ ).

In line with Luna et al. (2018), there was a main effect of experimental block for mean RT,  $F(3.94, 441.51) = 8.47$ ,  $p < .001$ ,  $\eta^2 = .07$ , standard deviation of the RT,  $F(4.18, 468.41) = 7.46$ ,  $p < .001$ ,  $\eta^2 = .06$ , and percentage of lapses,  $F(3.46, 387.16) = 14.38$ ,  $p < .001$ ,  $\eta^2 = .11$ . All these variables increased linearly across the blocks, namely mean RT,  $t(112) = 4.56$ ,  $p < .001$ , standard deviation of the RT,  $t(112) = 5.13$ ,  $p = .001$ , and percentage of lapses,  $t(112) = 5.68$ ,  $p < .001$ . Reliability for the three indexes of slope ranged from  $r_{SB} = .54$  to  $r_{SB} = .78$ .

Like for AV overall performance, only the cBAARS-IV exhibited significant correlations with indexes of AV slopes, concretely, with the slope of mean RT,  $\tau(111) = .17$ ,  $p = .004$ , and the slope of percentage of lapses,  $\tau(111) = .18$ ,  $p = .002$ ; but not with the slope of standard deviation of the RT ( $p = .099$ ). No significant correlations were found between the two other self-reports (i.e., the aBAARS-IV and the ASRS-5) and the three measures of AV slope (all  $p > .169$ ).

### *ID outcomes*

In the same vein as Forster and Lavie (2016), participants were slower in the presence ( $M = 640$ ,  $SD = 103$ ) versus in the absence ( $M = 608$ ,  $SD = 103$ ) of the irrelevant distractor,  $t(101) = 7.14$ ,  $p < .001$ ,  $d = 0.71$ . Nevertheless, both conditions did not significantly differ in the percentage of errors,  $t(101) = 0.95$ ,  $p = .342$ ,  $d = 0.09$ . Reliability for indexes of percentage increase in mean RT ( $r_{SB} = .21$ ) and percentage errors ( $r_{SB} = .03$ ) was found to be low. Contrary to our predictions, none of the three self-reports correlated with either percentage increase in mean RT (all  $p > .310$ ) or percentage errors (all  $p > .240$ ).

## **Discussion**

This study aimed at analysing the main attentional processes related to ADHD symptoms, namely attentional networks, executive and arousal vigilance, and distraction. To do so, we modified a single, fine-grained task (i.e., the ANTI-Vea) to add a distraction component (Forster & Lavie, 2016). Based on a dimensional model of ADHD, we employed a community sample of undergraduates and measured retrospective and current subjective ADHD symptoms. Although the ANTI-Vea worked successfully, the reliability was reduced for many indexes. A significant relation was observed between ADHD symptoms and a higher alerting effect, but not orienting or congruency effects. ADHD symptom ratings also related to a poorer performance over time in EV and to alterations in different AV measures. No association was found between ADHD symptoms and irrelevant distraction. Worthy of note, our pattern of results was not consistent across the three ADHD symptom self-reports or the specific task indexes. Therefore, our hypotheses were supported only partially. These findings have implications for the neurocognitive mechanisms of ADHD symptoms and for the role of the ANTI-Vea in this literature.

### **Attentional networks**

In line with our hypothesis, the finding of a higher alerting effect associated with ADHD symptoms is consistent with Berger and Posner's (2000) predictions. It also fits

the state regulation deficit account of ADHD (Sergeant, 2000, 2005; Sonuga-Barke, Wiersema, van der Meere, & Roeyers, 2010). From this view, a task context such as the ANTI-Vea, which has been shown to be suitable to measure vigilance decrement, would tend to induce underactivation. This state would be especially detrimental for the tonic arousal or activation in individuals with higher ADHD symptoms. As a consequence, environmental stimulation, such as warning signals, would compensate for that underactivated state, thereby bringing performance to normal levels. Although impaired alerting network is well established in ADHD children (Arora et al., 2020), this phenomenon has been less frequently reported in adults with ADHD (Oberlin et al., 2005). Our findings are inconsistent with Zamani Sani et al.'s (2020) report of no association between alerting network with ADHD symptoms in non-clinical adults, despite they had higher statistical power than us. Differences in the task length or difficulty, in the type of warning signal (auditory vs. visual), or in the measure of ADHD symptoms (childhood vs. adulthood) could help explain these contradictory findings.

The lack of an association between ADHD symptoms and the orienting effect in our data is theoretically and empirically consistent with previous literature (Arora et al., 2020; Berger & Posner, 2000; Lundervold et al., 2011; Zamani Sani et al., 2020). Of note, most research uses the original ANT, which provides a global index of orienting network. However, tasks such as the ANTI or the ANTI-Vea specifically assesses exogenous orienting, which is related to automatic processes (Ishigami et al., 2016). The scarce research on exogenous orienting in ADHD has failed to find alterations in children (Casagrande et al., 2012; Mullane et al., 2011), which is consonant with our results with symptoms in non-clinical adults.

Contrary to our hypothesis, we could not find an association between ADHD symptoms and the congruency effect. Indeed, executive attention has been hypothesized to be deficient in ADHD (Berger & Posner, 2000), and evidence using the ANT in children (Arora et al., 2020) and adults (Lampe et al., 2007; Oberlin et al., 2005; but see Lundervold et al., 2011) has supported this notion. However, both Zamani Sani et al. (2020) and us failed to extend those findings to non-clinical samples. From a dimensional view of ADHD, it could be argued that the association between executive attention and ADHD symptoms is not sufficiently meaningful in non-clinical adults. In parallel, we believe that the difference between tasks is highly relevant in this regard. In the ANT/ANTI, the flanker task is performed as a single task whose only goal is to respond to the target direction. By contrast, the ANTI-Vea incorporates a second goal into the mindset, which is simultaneous to the first one – namely to respond to the vertical displacement of the target. This increase in working memory load has been found to reduce the flanker interference, leading to a lower congruency effect (Luna, Telga, Telga, Vadillo, & Lupiáñez, 2020). Indeed, the congruency effect we obtained for RT and percentage errors was less than half of the usually reported in the ANT in non-clinical adults (MacLeod et al., 2010). This substantially lower congruency effect probably makes the index less sensitive to modulation from individual differences, such as ADHD symptoms, which is a concern about the ANTI-Vea to bear in mind. Alternatively, this result could be interpreted in the sense that adults with higher ADHD symptom scores, when appropriately challenged by task demands, as in the ANTI-Vea task, can overcome any putative executive deficit they might have.

### **Executive and arousal vigilance**

Partial support for our hypothesis of a poorer EV associated with ADHD symptoms was limited to indexes of performance over time (i.e., vigilance decrement). This is consonant with Craig and Klein's (2019) finding in non-clinical adults. However, this is rather the opposite pattern as Huang-Pollock et al.'s (2012) meta-analysis with ADHD children, who found larger deficits in overall performance than in performance over time. Performance over time is considered the appropriate form to measure vigilance (Huang-Pollock et al., 2012; Tucha et al., 2017), although numerous tasks used in ADHD research have failed to measure it (Johnson et al., 2001; Marchetta et al., 2008; Tucha et al., 2017). However, the ANTI-Vea task has been specifically developed to induce such vigilance decrement. Further research comparing clinical ADHD with non-clinical controls in the ANTI-Vea is likely to find larger and more consistent differences in vigilance decrement than previously reported.

Different from other EV tasks, vigilance decrement in the ANTI-Vea mainly manifests as a change to a more conservative response criterion, rather than a loss of sensitivity<sup>4</sup>. However, our data showed ADHD symptoms to be associated with a decrement of sensitivity over the task, but not with a more conservative response style – indeed, we observed the opposite trend. This pattern, consistent with clinical research (Huang-Pollock et al., 2012, 2020), suggests that EV impairments in ADHD symptoms are more a matter of sensitivity than a response bias (Thomson, Besner, & Smilek, 2016). However, the relatively low rate of false alarms in this literature prevents us from ruling out a floor effect that might be overestimating the role of sensitivity at the expense of underestimating the role of response criterion. Indeed, Luna, Roca, et al. (2020) found a drop in sensitivity only among those participants with a percentage of false alarms close to the floor ( $\leq 5\%$ ) in the first block, but not for the rest of participants. A similar pattern was observed in our data.

Furthermore, we found ADHD symptoms – only retrospectively reported in childhood – to be associated with a diminished AV, in both mean RT and response variability (i.e., standard deviation and percentage of lapses). These results support our hypothesis and are consonant with the scarce clinical research comparing adults with ADHD in overall and over time AV measures of response variability (Gmehlin et al., 2016; Tucha et al., 2017). However, different from clinical studies, we also found that a greater increment of mean RT was positively associated with ADHD symptoms. As in the case of EV, the fact that the ANTI-Vea is the only task of this literature that generates decrement in AV might account for such discrepancies. Moreover, higher response variability associated with ADHD is ubiquitous to multiple types of tasks (Epstein et al., 2011; Kofler et al., 2013). Our data extended this phenomenon to symptoms in non-clinical adults in an AV task that is embedded in a complex structure (i.e., the ANTI-Vea).

The relationship between EV and AV is also relevant to the field of ADHD. Grounded on van Zomeren and Brouwer's (1994) attentional model, Gmehlin et al. (2016) argued that sustained alertness (strongly related to AV) is a precondition for more complex attentional functions over time – including processes that could be considered as components of EV. According to this view, Gmehlin et al. found that, when controlling for the slope of AV (i.e., change in percentage of lapses across blocks), differences between ADHD and control groups in EV disappeared. By contrast, there is evidence supporting that EV and

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<sup>4</sup> Although a loss of sensitivity over the task has been reported in our data as well as in studies with high statistical power (Feltmate et al., 2020; Luna, Roca, et al., 2020), this effect size seems to be lower than the effect on the response criterion.

AV, albeit probably related, constitute independent components of vigilance (Luna, 2019; Luna, Román-Caballero, et al., 2020; Sanchís et al., 2020). In our data, an equivalence test (Lakens, 2017) showed that the correlation of  $r(111) = -.06$  between the slopes of hits (EV) and lapses (AV) fell below the upper bound of  $r = .1$  ( $p = .044$ ). This suggests that EV and AV do not depend on each other in a meaningful way. Furthermore, the partial correlation between ADHD symptoms (ASRS-5) and the slope of the percentage of hits, controlling for the percentage of lapses, remained significant,  $\tau(110) = -.11, p = .037$ . This result, inconsistent with Gmehlin et al., does not support the idea of AV as a prerequisite for EV and could be in line with the notion of ADHD as a heterogeneous condition (Fair, Bathula, Nikolas, & Nigg, 2012).

### ***Irrelevant distraction***

Although we found an acceptable effect of ID on the RT, the lack of correlation with ADHD symptoms does not support our hypothesis, and it is contrary to Forster and Lavie's (2016) findings. In fact, our results are in line with Meier's (2020) failed attempt to replicate Forster and Lavie's results using exactly the same task and a similar sample composition (i.e., university students). Against the case of a Forster and Lavie's false positive, it should be noted that they also found a positive correlation in a second experiment with a different task as well as in a case-control study comparing ADHD with controls (Forster et al., 2014). Therefore, the possibility of a true effect is still likely. Regarding the event of a false negative in Meier's and our study, assuming the effect found by Forster and Lavie ( $r = .32$ ), a very high statistical power was achieved by Meier (.99) and us (.95). Moreover, Meier found Bayesian evidence favouring the null hypothesis. Of note, the reliability of the ID index reported by Meier and us was rather low ( $r_{SB} = .26$  and  $.21$ , respectively). This importantly reduces the size of the observed correlation with ADHD symptoms, leading to the need for a larger sample size and higher reliability scores to reach the desired power (Parsons et al., 2019). Further studies are warranted not only to consistently determine the existence of a positive correlation between the ID effect and ADHD symptoms, but also to test whether this correlation is stronger than those using task-relevant distractors (e.g., flanker task).

### ***Measuring ADHD symptoms in childhood and adulthood***

To gain a better knowledge of ADHD symptomatology, we used three different but complementary measures: one for symptoms in childhood (cBAARS-IV) and the other two for symptoms in adulthood (aBAARS-IV and ASRS-5). Characterizing developmental trajectories in ADHD is important to obtain more homogeneous subgroups and phenotypes, also at the neurocognitive level (Luo et al., 2019; Sonuga-Barke & Halperin, 2010). In a longitudinal study, Moffitt et al. (2015) found that ADHD in childhood had very little overlap with the adult-onset form of ADHD. Moreover, at age 38, only participants with ADHD in childhood showed neuropsychological deficits, including overall performance in EV. Although EV was the only domain where we found poorer performance to be associated with ADHD symptoms in adulthood but not in childhood, our altered EV indexes were of performance over time. In fact, our general picture of results differentiated ADHD symptoms in childhood versus in adulthood. While the former predicted alterations in arousal (i.e., alerting network and AV), the latter were negatively associated with executive outcomes (i.e., EV decrement). This dissociation is, to some extent, consonant with Halperin and Schulz's (2006) neurodevelopmental model of



ADHD. This model postulates that, while the early onset of the disorder is associated with subcortical structures involving arousal, the persistence of the ADHD in the adulthood is related to prefrontal regions which underlie executive processes. The fact that this model could explain developmental differences in the neuropsychological correlates of non-clinical symptoms coheres with the dimensional nature of ADHD.

Within ADHD symptoms in adults, it is noteworthy that, while the ASRS-5 yielded some significant correlations with ANTI-Vea measures, the aBAARS-IV did not. Besides the possible statistical errors that will be mentioned in the next section, a tentative account is related to the different form of both self-reports to measure adult ADHD symptoms. The aBAARS-IV uses the 18 DSM-IV criteria (without examples) as items. The content of these items is generic for children and adults. By contrast, the ASRS-5 is not only based on DSM-5 criteria, which better reflect the adult presentation, but also include items specifically designed to detect ADHD in adults (Ustun et al., 2017). Therefore, instead of a lack of relationship between adult ADHD symptoms and neuropsychological deficits, it might be that highly sensitive self-reports are needed to accurately capture the adult presentation of ADHD symptomatology, along with its underlying alterations.

### **Limitations**

We have identified four main caveats in our study. The first one regards the generalization of our findings. Our community sample consisted of undergraduates, with a majority of women. Not only are both sociodemographic characteristics unrepresentative of the general population, but they also are negatively correlated with ADHD symptom severity (Arnett, Pennington, Willcutt, DeFries, & Olson, 2015; Birchwood & Daley, 2012). Despite this sampling bias, our statistical analyses do not suggest that the distribution of ADHD symptoms in our sample is meaningfully more homogeneous – and less sensitive to correlate with behavioural tasks – than in a representative community sample. Moreover, only two out of our 120 participants (i.e., 1.6%) had the diagnosis of ADHD. While this proportion is lower than the estimated worldwide prevalence of the disorder in adults (3.6%), it is close to the Spanish prevalence (1.2%; Fayyad et al., 2017). Of note, a study conducted at a Spanish primary care centre found an extremely low prevalence (0.04%) of registered ADHD diagnoses in adults (Aragonès et al., 2010). In any case, our unsubstantial number of potential participants with ADHD prevents our results from having direct implications for clinical ADHD research and practice. Therefore, replications of our findings with more representative samples including a substantial amount of ADHD individuals are warranted.

The second concern has to do with the construct validity of ADHD symptoms in our study. We failed to assess relevant symptoms such as depression or anxiety and did not ask for other psychiatric disorders. Thus, it is not clear to what degree the ratings obtained from our sample validly reflect an ADHD symptom status rather than a general psychological distress severity. In fact, symptoms of depression and anxiety have been linked to ADHD symptoms (Combs, Canu, Broman-Fulks, Rocheleau, & Nieman, 2015), and ADHD diagnosis requires that its symptoms be not better explained by another disorder such as mood or anxiety disorders (APA, 2013). Ultimately, we cannot rule out that the relation found between ADHD symptoms and attentional functioning in our study might be a by-product of a third construct (e.g., depression, stress, other disorders, intelligence, sociodemographic factors). Future research should properly assess and control for these potential confounders as well as incorporate measures of ADHD symptoms beyond self-reported questionnaires (i.e., other-reports, clinical interviews).

Third, the general picture of correlations between attentional processes and ADHD symptom self-reports shows that, at best, our hypotheses were supported only partially. That is, no attentional domain exhibited significant correlations with ADHD symptoms across the three self-reports. Also, for those observed significant correlations the effect sizes were at most small to medium. Besides the sampling bias discussed above, a more plausible reason is related to the psychometric properties of the ANTI-Vea indexes. Although our task reliability scores are similar to the ones reported in Luna, Roca, et al. (2020), the reliability found for difference scores and slopes tended to be fairly low. This limitation, which is also inherent to most cognitive tasks (Dang, King, & Inzlicht, 2020; Hedge, Powell, & Sumner, 2018), could dramatically attenuate the observed correlations coefficients. Futures studies should either attempt to improve the reliability of their tasks or use valid methods to correct for low reliability to estimate the true correlation between ADHD symptoms and attentional processes.

The fourth limitation concerns the control of the type I error rate in our results. Since our study did not reach a very high statistical power, strict corrections for multiple comparisons were likely to dramatically increase the rate of false negatives. Following McDonald's (2014) suggestion, we conducted an exploratory secondary analysis where we applied the Benjamini–Hochberg procedure (Benjamini & Hochberg, 1995) to our correlation matrix in order to control for a false discovery rate of 20%. Groups for multiple comparisons were set according to our hypotheses. The significant findings of this corrected pattern of correlations are roughly similar to such comparisons before the correction (see Table S3). In any case, to attain a more proper control of both types of statistical errors, our study needs to be replicated with a larger sample.

## **Conclusion**

To conclude, our modified version of the ANTI-Vea was useful for measuring the functioning of the attentional networks, executive and arousal vigilance, and irrelevant distraction. This fine-grained distinction between attentional processes is relevant to gain a depth understanding of the mechanisms underlying ADHD symptomatology. In a sample of undergraduates, we found that subjective ADHD symptoms in childhood were related to alerting and arousal processes, while symptoms in adulthood were rather associated with the executive component of vigilance. Different from other neuropsychological tasks, the ANTI-Vea could successfully induce vigilance decrement. However, compared to other tasks (e.g., ANT), our index of the executive attentional network (i.e., congruency effect) was fairly reduced by task demands. Moreover, some of the task indexes (especially those involving difference scores) exhibited poor reliability. Although replications with larger and clinical samples are necessary, this thorough approach to the attentional processes underlying ADHD symptoms might shed light on the search for more homogeneous subgroups of the disorder.

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### Conflicts of interest

All authors declare no conflict of interest.

### Author contributions

Tao Coll-Martín (Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Software; Visualization; Writing – original draft) Hugo Carretero-Dios (Formal analysis; Funding acquisition; Project administration; Supervision; Validation; Writing – review & editing) Juan Lupiáñez (Conceptualization; Funding acquisition; Methodology; Project administration; Resources; Supervision; Validation; Writing – review & editing).

### Data availability statement

The data and materials that support the findings of this study are openly available in the Open Science Framework at <https://osf.io/k8jdm/>

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### **Supporting Information**

The following supporting information may be found in the online edition of the article:

Text S1 ADHD symptom distribution in the present study compared to an estimated normative distribution

Text S2 Irrelevant distractor position and attention-deficit/hyperactivity disorder symptoms: An exploratory analysis

Table S1 Percentiles values of the cBAARS-IV and the aBAARS-IV in original and estimated normative samples compared to the sample of the present study

Table S2 Kendall's rank correlations among ANTI-Vea outcomes

Table S3 Kendall's rank correlations between ANTI-Vea outcomes and ADHD symptoms with corrections for multiple comparisons

Figure S1 Q-Q plots comparing ADHD symptom distribution in our sample with symptom distribution in an estimated normative sample for the cBAARS-IV (Panel A) and the aBAARS-IV (Panel B)