



Event-related potentials associated with attentional and vigilance components

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Abstract:	Attentional networks are regulated by three independent but interacting sub-systems, i.e., alertness and vigilance, orienting, and executive control. While most of the studies analyzing event-related potentials (ERPs) of attentional networks focused on classic attentional functions (i.e., phasic alertness, orienting, and executive control), ERPs associated with vigilance were measured in separated studies and with different behavioral paradigms. The present study aimed at determining ERPs related to attentional and vigilance components of the attentional networks system. Forty participants (34 women, age: M = 25.96; SD = 4.96) completed two experimental sessions wherein electroencephalographic signal was recorded while they completed the Attentional Networks Test for Interactions and Vigilance – executive and arousal components, a behavioral task suitable for measuring the independence and interactions of the classic attentional components as well as the executive (i.e., the ability to detect infrequent critical signals) and arousal (i.e., the capacity to sustain a fast reaction to environmental stimuli) vigilance components. Independent ERPs previously reported for the classic attentional components were replicated here: (a) N1, P2, and contingent negative variation for phasic alertness; (b) P1, N1, and P3 for

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	<p>orienting; and (c) N2 and slow positivity for executive control. Importantly, vigilance components were associated with different ERPs: while the executive vigilance decrement was associated with an increase in P3 and slow positivity across time-on-task, reduced arousal vigilance was associated with reduced N1 and P2 amplitude. The present study provides novel and high-powered evidence about specific neural mechanisms underlying multiple components of the attentional networks system.</p>



Impact statements

This study demonstrates that **specific** attentional and vigilance ERPs can be simultaneously observed within a single session. Classic attentional components were associated with ERPs involved in early sensory processing, attentional preparation, target anticipation and processing, and conflict detection and resolution. Critically, **different** ERPs were observed for vigilance components: whereas executive vigilance loss was associated with late ERPs' amplitude increases, reduced arousal vigilance was associated with early ERPs' amplitude decreases.

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4 1 **Title**

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38 17 **Short title**

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Abstract

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7 27 Attentional networks are regulated by three independent but interacting sub-systems,
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14 31 with vigilance were measured in separated studies and with different behavioral paradigms.
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20 34 completed two experimental sessions wherein electroencephalographic signal was recorded
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22 35 while they completed the Attentional Networks Test for Interactions and Vigilance –
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24 36 executive and arousal components, a behavioral task suitable for measuring the independence
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26 37 and interactions of the classic attentional components as well as the executive (i.e., the ability
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28 38 to detect infrequent critical signals) and arousal (i.e., the capacity to sustain a fast reaction to
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30 39 environmental stimuli) vigilance components. Independent ERPs previously reported for the
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32 40 classic attentional components were replicated here: (a) N1, P2, and contingent negative
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34 41 variation for phasic alertness; (b) P1, N1, and P3 for orienting; and (c) N2 and slow positivity
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36 42 for executive control. Importantly, **vigilance components were associated with different**
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38 43 **ERPs**: while the executive vigilance decrement was associated with an increase in P3 and
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40 44 slow positivity across time-on-task, reduced arousal vigilance was associated with reduced
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42 45 N1 and P2 amplitude. The present study provides novel and high-powered evidence about
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44 46 **specific** neural mechanisms underlying multiple components of the attentional networks
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1. Introduction

The attentional networks system comprises three relatively independent networks (i.e., alertness and vigilance, orienting, and executive control) that detect, select, and organize internal and external information received to adapt our behavior to the environment (S. E. Petersen & Posner, 2012; Posner & Dehaene, 1994; Posner & Petersen, 1990). Aiming at **determining** the neural mechanisms underlying attentional components (Posner, 2012; Posner et al., 2006; Raz & Buhle, 2006), there has been considerable interest in examining event-related potentials (ERPs) associated with each of the three attentional networks (Abundis-Gutiérrez et al., 2014; Galvao-Carmona et al., 2014; Gonçalves et al., 2018; Neuhaus et al., 2010; Zani & Proverbio, 2017; Zhang et al., 2018). Importantly, while most of these studies have particularly examined ERPs associated with classic attentional components (i.e., phasic alertness, attentional orienting, and executive control), ERPs associated with vigilance have been studied in relative isolation and via different behavioral methods, i.e., by measuring vigilance either with signal-detection (Boksem et al., 2005; Reteig et al., 2019) or single reaction time (RT) (Hoedlmoser et al., 2011; Ramautar et al., 2013; Witkowski et al., 2015) tasks. In the present study, by combining different methodological approaches used in previous research (Abundis-Gutiérrez et al., 2014; Lara et al., 2018; Ramautar et al., 2013), we examined ERPs in multiple attentional and vigilance components simultaneously observed with the same task, to therefore further **determine specific** neural mechanisms of attentional networks.

Attentional networks-associated ERPs have been previously examined using the attentional networks test (ANT) (Galvao-Carmona et al., 2014; Gonçalves et al., 2018; Neuhaus et al., 2010; Zani & Proverbio, 2017; Zhang et al., 2018) or its variation for measuring the interactions among the networks (ANTI) (Abundis-Gutiérrez et al., 2014). In short, these tasks present warning signals and visual spatial cues –to assess phasic alertness

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3 73 and attentional orienting, respectively– which might anticipate the target of a flanker
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5 74 paradigm, thus measuring executive control (Callejas et al., 2004; Fan et al., 2002). ERPs
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7 75 evidence on the alertness and vigilance network –which connects the locus coeruleus with
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9 76 parietal and prefrontal cortices (Fan et al., 2005; Posner, 2008)– has mainly targeted phasic
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11 77 alertness functioning, i.e., brief changes of alertness induced by external warning signals
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13 78 (Posner, 2008). While visual warning cues (i.e., a double asterisk in the ANT) **have been**
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15 79 shown to increase early perceptual/attentional components such as P1 and N1 (Gonçalves et
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17 80 al., 2018; Neuhaus et al., 2010), auditory warning signals (i.e., the alertness tone in the
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19 81 ANTI) also elicit a contingent negative variation (CNV) in central-frontal regions that
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21 82 anticipates the target (Abundis-Gutiérrez et al., 2014). For the orienting network –modulated
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23 83 by activity in sub-cortical (i.e., the superior colliculus and the pulvinar nuclei of the
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25 84 thalamus) and cortical (i.e., the frontal eye fields and the posterior parietal cortex) regions
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27 85 (Fan et al., 2005; Posner, 2016)–, evidence suggests that visual spatial cues modulate P1 and
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29 86 N1 in occipital regions for early target detection (Galvao-Carmona et al., 2014; Gonçalves et
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31 87 al., 2018; Neuhaus et al., 2010). Interestingly, Abundis-Gutiérrez et al. (2014) also observed
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33 88 that invalid spatial cues reorient target localization by increasing P3 amplitude in central-
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35 89 parietal regions compared to valid cues.
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43 90 Regarding the executive control network –spanning the anterior cingulate and the
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45 91 dorsolateral prefrontal cortex (Botvinick et al., 2004; Fan et al., 2005; Shenhav et al., 2013)–,
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47 92 changes in late ERPs were observed for conflict detection and resolution (Abundis-Gutiérrez
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49 93 et al., 2014; Gonçalves et al., 2018; Neuhaus et al., 2010; Zani & Proverbio, 2017). Some
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51 94 studies reported that P3 modulates distractor inhibition at parietal (Gonçalves et al., 2018)
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53 95 and also frontal (Neuhaus et al., 2010) central regions. Within this network, Abundis-
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55 96 Gutiérrez et al. (2014) dissociated two mechanisms: conflict detection is indexed by an N2 at
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57 97 central-frontal regions, while conflict resolution seems to be associated with a late amplitude
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3 98 decrease (i.e., the so-called slow positivity component, SP) at central and parietal areas.

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5 99 Importantly, previous studies also examined modulations of phasic alertness or attentional

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7 100 orienting on the executive control network (Abundis-Gutiérrez et al., 2014; Zani &

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9 101 Proverbio, 2017). While Abundis-Gutiérrez et al. found no modulation of phasic alertness or

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11 102 attentional orienting over N2 and SP executive control components, Zani & Proverbio (2017)

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13 103 reported that SP was earlier in the predictive spatial cue condition, showing some benefits of

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15 104 attentional orienting on conflict resolution.

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20 105 In studies with the ANT or the ANTI task, vigilance –i.e., the capacity to sustain

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22 106 attention over long periods (Hancock, 2017; Posner, 2008)– is measured indirectly, as the

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24 107 behavioral (Fan et al., 2002; Ishigami & Klein, 2010) and neural (Galvao-Carmona et al.,

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26 108 2014; Zani & Proverbio, 2017) responses in the absence of warning and visual signals. As no

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28 109 direct and independent measure of vigilance is usually obtained with these tasks, determining

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30 110 the neural mechanisms of vigilance within the attentional networks system has been

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32 111 challenging. Moreover, vigilance is not conceived as a unitary concept (Esterman & Rothlein,

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34 112 2019; Oken et al., 2006; Sarter et al., 2001; Shallice et al., 2008; Sturm & Willmes, 2001; van

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36 113 Schie et al., 2021). Two different components of vigilance have been identified: executive

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38 114 vigilance, as the ability to detect infrequent targets from noise stimuli during long periods,

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40 115 and arousal vigilance, as the capacity to sustain a fast reaction to environmental stimuli

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42 116 without implementing much control on responses (Luna et al., 2018). Vigilance components

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44 117 are usually measured by different behavioral tasks (Luna et al., 2018; Posner, 2008; Roca et

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46 118 al., 2011). While signal-detection tasks such as the Sustained Attention to Response Task

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48 119 (Robertson et al., 1997) particularly measure executive vigilance, single RT tasks such as the

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50 120 Psychomotor Vigilance Test (Lim & Dinges, 2008) measure arousal vigilance.

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53 121 Previous research measuring vigilance with signal-detection tasks such as the

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59 122 Sustained Attention to Response Task has found differences in early and late ERPs among

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3 123 hits on infrequent signals and correct rejections on noise (i.e., the absence of infrequent
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5 124 signal) events, thus showing specific neural responses for categorizing signal and noise
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8 125 stimuli (Karamacoska et al., 2019; McMackin et al., 2020; Reteig et al., 2019). Nonetheless,
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10 126 evidence is both scarce and inconsistent regarding whether the decrease in hits (i.e., the
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12 127 behavioral index of the executive vigilance decrement) is accompanied by a change in ERPs
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15 128 across time-on-task. [Although Boksem et al. \(2005\) observed a general change in N1 and N2](#)
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17 129 [amplitudes across time-on-task, these changes were not specifically associated with hits in](#)
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19 130 [their vigilance task.](#) Lara et al. (2018) observed an increase in N1 and a decrease in N2
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21 131 amplitude as task progressed. However, note that in the study by Lara et al. no decrement in
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23 132 hits across time on task was observed, so changes in ERPs were not accompanied by a
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25 133 decrease in behavioral responses. Interestingly, Bonnefond et al. (2010) observed an increase
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27 134 in a late P1 component (at 550-850 ms) with time-on-task in trials that anticipated an
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29 135 infrequent critical signal, an outcome interpreted as an increase in attentional resources for
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31 136 sustaining an optimal performance during long periods.
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36 137 In contrast, the vigilance decrement measured with single RT tasks such as the
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38 138 Psychomotor Vigilance Test has been associated with changes in early and late ERPs
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40 139 (Hoedlmoser et al., 2011; Ramautar et al., 2013; Witkowski et al., 2015). Note that,
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42 140 importantly, in previous studies with single RT tasks both behavioral and neural changes
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44 141 were observed across several sessions during a night (Hoedlmoser et al., 2011; Ramautar et
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46 142 al., 2013) or even weeks (Witkowski et al., 2015). In studies where the vigilance decrement
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48 143 was assessed over one night of sleep-deprivation, while Hoedlmoser et al. (2011) observed a
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50 144 decrease in P1 but not N1 at occipital regions, Ramautar et al. (2013) observed a reduced P3
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52 145 peak-latency at central-parietal locations for sleep-deprived participants in contrast to normal-
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54 146 sleep ones. Interestingly, Witkowski et al. (2015) showed that vigilance impairments during
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3 147 the course of a college semester were accompanied by a decrease in P3 at parieto-occipital
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5 148 regions when performing the Psychomotor Vigilance Test.
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9 149 **1.1. The present study**

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12 150 Given that previous research on ERPs associated with the attentional networks system
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14 151 has not directly measured vigilance performance (Abundis-Gutiérrez et al., 2014; Galvao-
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16 152 Carmona et al., 2014; Gonçalves et al., 2018; Neuhaus et al., 2010; Zani & Proverbio, 2017)
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18 153 and, importantly, since vigilance is not considered a unitary concept (Luna et al., 2018; Oken
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20 154 et al., 2006; Sarter et al., 2001; van Schie et al., 2021) and it is usually measured using
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22 155 different behavioral tasks (Lim & Dinges, 2008; Posner, 2008; Robertson et al., 1997), we
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24 156 decided to conduct the present study. Aiming at further [examining ERPs associated with](#)
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26 157 attentional and vigilance components (S. E. Petersen & Posner, 2012; Posner et al., 2006;
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28 158 Posner, 2012), we used the newest and fine-grained version of the ANT, i.e., the Attentional
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30 159 Networks Test for Interactions and Vigilance – executive and arousal components (ANTI-
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32 160 Vea, Luna et al., 2018; for a review on the ANT and its variations, see de Souza Almeida et
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34 161 al., 2021). The ANTI-Vea combines three behavioral tasks within a single session, in
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36 162 particular: (a) the ANTI of Callejas et al. (2004) to assess the independence and interactions
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38 163 of classic attentional components, (b) a signal-detection task similar to the Sustained
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40 164 Attention to Response Task (Robertson et al., 1997), suitable to assess executive vigilance,
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42 165 and (c) a single RT task as the Psychomotor Vigilance Test (Lim & Dinges, 2008) to assess
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44 166 arousal vigilance. Importantly, to increase the electroencephalographic (EEG) signal/noise
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46 167 ratio, we decided to run and collapse two experimental sessions per participant.
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54 168 The ANTI-Vea is suitable to assess the typical main effects and interactions of the
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56 169 classic attentional components while measuring the decrement in executive vigilance –as a
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58 170 progressive drop in hits– and arousal vigilance –as a linear increase in mean and variability of
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3 171 RT– across time-on-task within a single session (Feltmate et al., 2020; Luna et al., 2018;
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5 172 Luna, Barttfeld, et al., 2021; Román-Caballero et al., 2021), both in the typical lab conditions
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7 173 and outside the lab in an online session (Luna, Roca, et al., 2021). Most importantly, prior
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9 174 studies have shown dissociable mechanisms on executive and arousal vigilance at the neural
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11 175 and physiological levels: while anodal transcranial direct current stimulation over the right
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13 176 fronto-parietal networks mitigated specifically the executive but not the arousal vigilance
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15 177 decrement (Hemmerich et al., 2021; Luna et al., 2020), moderate exercise reduced the
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17 178 executive vigilance decrement and caffeine intake mitigated the arousal vigilance decrement
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19 179 across time-on-task (Sanchis et al., 2020).

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24 180 We expected to find similar ERPs to those previously observed with similar
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26 181 attentional or vigilance behavioral paradigms in previous studies (see a summary of our
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28 182 predictions in Table 1). In particular, we expected similar ERPs for the independence and
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30 183 interactions of the classic attentional components as in Abundis-Gutiérrez et al. (2014), as we
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32 184 measured phasic alertness, orienting, and executive control using the same ANTI task
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34 185 (Callejas et al., 2004). For vigilance components, we expected to observe different changes in
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36 186 ERPs across time-on-task for executive and arousal vigilance. However, previous evidence
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38 187 about changes in ERPs across time-on-task in signal-detection tasks measuring executive
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40 188 vigilance is inconsistent, as for instance, either a decrease in P3 (Lara et al., 2018) or an
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42 189 increase in late P1 (Bonnefond et al., 2010) have been reported. Unlike our study, single RT
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44 190 tasks capturing arousal vigilance measured ERPs changes in several sessions across hours
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46 191 (Hoedlmoser et al., 2011; Ramautar et al., 2013) or even weeks (Witkowski et al., 2015),
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48 192 showing a decrease in P1 (Hoedlmoser et al., 2011) or P3 (Ramautar et al., 2013; Witkowski
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50 193 et al., 2015). Therefore, and importantly, measuring vigilance with different tasks and in
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52 194 different moments will be affected by unrelated changes in the vigilance state, which makes
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54 195 comparing ERPs' changes difficult. Consequently, an important and crucial aspect of our
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3 196 study is measuring executive and arousal vigilance using the same task within the same
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5 197 session. Taking all these into account, in the present study, we decided to examine ERPs
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7 198 associated with executive and arousal vigilance in regions previously examined in vigilance
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9 199 research. We expect the present study to provide novel and more precise evidence on the
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11 200 ERPs associated with the attentional networks system (S. E. Petersen & Posner, 2012; Posner
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13 201 et al., 2006; Posner, 2012).

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18 202 *Please, insert Table 1 here.*

20 203 **2. Method**

23 204 **2.1. Participants**

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26 205 Sample size was a-priori estimated based on previous studies with the ANTI-Vea in
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28 206 which the decrement in hits across blocks showed an effect size of $\eta_p^2 = .05$ with 40
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30 207 participants per group (Luna et al., 2018; Luna, Barttfeld, et al., 2021). Using G*Power
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32 208 3.1.9.4 (Faul et al., 2007), power analysis showed that considering $\alpha = .05$ and $1 - \beta = .90$, the
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34 209 minimum sample size required to observe an effect size of $\eta_p^2 = .05$ with two sessions and
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36 210 seven blocks was 35 participants. *Given that participants performed more than twice as many*
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38 211 *trials than in previous studies (two sessions of seven blocks, instead of a single session of six*
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40 212 *blocks), our study had a much higher power than previous studies (Baker et al., 2021).*

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43 213 Therefore, a total of 40 (34 women) healthy adults (age: $M = 25.96$; $SD = 4.96$), who
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45 214 were undergraduate or graduate students from the Universidad Nacional de Córdoba,
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47 215 Argentina, volunteered to participate in the present study. They had normal or corrected to
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49 216 normal vision and none of them had a history of neurological or psychiatric illness. All
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51 217 participants signed an informed consent approved by the local ethics committee. The study
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53 218 was conducted according to the ethical standards of the 1964 Declaration of Helsinki (last
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55 219 update: Seoul, 2008) and was positively evaluated by a local ethics committee (Comité

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3 220 Institucional de Ética de Investigaciones en Salud of the Hospital Nacional de Clínicas,
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5 221 CIEIS HNC, Universidad Nacional de Córdoba, Argentina).
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9 **222 2.2. Behavioral task: ANTI-Vea**

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12 223 The experimental task was designed and controlled with E-Prime 2.0 software
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14 224 (Psychology Software Tools, Pittsburgh, PA). The ANTI-Vea comprises three embedded
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16 225 subtasks: (a) ANTI (60%), a flanker task combined with an auditory warning signal and a
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18 226 visual spatial cueing paradigm suitable to assess the independence and interactions of phasic
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20 227 alertness, orienting, and executive control; (b) executive vigilance (20%), a signal-detection
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22 228 subtask similar to the Sustained Attention to Response Task wherein an infrequent critical
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24 229 signal has to be detected, thus measuring the executive vigilance decrement; and (c) arousal
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26 230 vigilance (20%), a RT subtask similar to the Psychomotor Vigilance Test suitable to assess
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28 231 the arousal vigilance decrement. The stimuli sequence and timing for the trials of each
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30 232 subtask are depicted in Fig. 1 and can be reviewed in detail in previous studies (Luna et al.,
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32 233 2018; Luna, Barttfeld, et al., 2021; Luna, Roca, et al., 2021).
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38 234 *Please, insert Figure 1 here.*

39 235 Participants were encouraged to fix on the fixation cross at all times. In the ANTI
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41 236 trials, which followed the procedure of the ANTI task (Callejas et al., 2004), a five-arrow
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43 237 horizontal string appeared either above or below the fixation point and participants had to
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45 238 select the direction (i.e., left/right) the central arrow (i.e., the target) pointed to, ignoring the
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47 239 direction pointed by the surrounding flanking arrows (see Fig. 1 panel d). To assess the
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49 240 executive control network, the direction of the target and flanking arrows were congruent in
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51 241 half of these trials and incongruent in the other half. To assess phasic alertness functioning, a
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53 242 tone (i.e., warning signal) could anticipate the target appearance in half of these trials,
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55 243 whereas no tone was presented in the other half (see Fig. 1 panel a). To assess the orienting
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3 244 network, the target's position (i.e., above/below the fixation point) could be preceded either
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5 245 by a valid (i.e., the same location in 1/3 of ANTI trials), an invalid (i.e., the opposite location
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7 246 in 1/3 of ANTI trials) spatial visual cue, or by no cue at all in the remaining 1/3 of ANTI
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9 247 trials (see Fig. 1 panel c). Importantly, note that valid and invalid conditions were
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11 248 counterbalanced regarding the position of the visual cue on the screen (i.e., above/below the
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13 249 fixation point).

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17 250 Executive vigilance trials were similar to the ANTI (see Fig. 1 panel a), except that
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19 251 the target was largely displaced (i.e., 8 pixels $-px-$) from its central position, either upwards
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21 252 or downwards (see Fig. 1 panel d). Executive vigilance trials mimic signal-detection tasks
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23 253 like Sustained Attention to Response Task: participants were instructed to remain vigilant and
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25 254 to detect the infrequent target's displacement by pressing the space bar, ignoring the direction
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27 255 the target pointed to. Lastly, arousal vigilance trials –which mimic the Psychomotor
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29 256 Vigilance Test– had the same timing than the ANTI and executive vigilance trials but,
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31 257 importantly, no warning signal nor visual cue was presented (i.e., the fixation point remained
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33 258 on the screen) and the response' stimuli of the ANTI/executive vigilance trials was replaced
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35 259 by a millisecond counter (see Fig. 1 panel b). In the arousal vigilance trials, participants had
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37 260 to stop the millisecond counter as fast as possible by pressing any key (see Fig. 1 panel d).

261 **2.3. EEG data acquisition and preprocessing**

262 EEG signal was recorded with a high density 128 channels BioSemi ActiveTwo
263 system, which was controlled with the ActiView software (BioSemi, Amsterdam). Two flat-
264 type active-electrodes were placed over the right and left mastoids as additional electrical
265 reference channels. Electrode impedances were kept below 1 Ohm. Signal was registered
266 with a sampling rate of 1024 Hz.

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3 267 EEG data pre-processing was conducted with EEGLAB v2020.0 toolbox (Delorme &
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5 268 Makeig, 2004) on MATLAB R2016a (The MathWorks, Inc.). Data format was first
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8 269 converted to the EEGLAB format and resampled at 512 Hz. Signals were filtered between 0.5
9
10 270 Hz and 45 Hz. Signal was decomposed into 128 components (i.e., the same number of
11
12 271 channels) using Independent Component Analysis. Then, using ADJUST v.1.1.1 (Mognon et
13
14 272 al., 2011), artifactual components were automatically classified as horizontal eye movements
15
16 273 ($M = 3.28$; $SD = 2.51$), vertical eye movements ($M = 6.85$; $SD = 5.35$), blinks ($M = 3.99$; SD
17
18 274 $= 3.24$), and generic discontinuities ($M = 14.85$; $SD = 8.56$), and were removed from signal.
19
20
21 275 We extracted 3400 ms epochs that were visually inspected to interpolate artifactual channels
22
23 276 or to reject the entire epoch if it was too noisy (trials rejected by participant in the collapsed
24
25
26 277 two sessions: $M = 10.88$; $SD = 18.13$).

278 2.4. Procedure and Design

279 Participants were first familiarized with the task by performing the online ANTI-Vea
280 version (<https://www.ugr.es/~neurocog/ANTI/>; Luna, Roca, et al., 2021) at any place of their
281 own choosing. Aiming at gathering a larger amount of within-participant measures of EEG
282 signal, two experimental sessions were completed at the lab (average time between sessions:
283 $M = 11.80$ days; $SD = 15.89$). Note that, importantly, the executive and arousal vigilance
284 decrements as well as the main effects and interactions of the classic attentional network
285 functions were observed with the ANTI-Vea in previous research with repeated-measures
286 across several sessions (Sanchis et al., 2020). At the lab, participants received the standard
287 instructions to correctly perform each type of trial and completed one practice block of 40 (24
288 ANTI, 8 executive vigilance and 8 arousal vigilance) randomly presented trials, without
289 visual feedback. Each experimental session comprised seven experimental blocks without
290 any pause or visual feedback, consisting in 80 (48 ANTI, 16 executive vigilance and 16

1
2
3 291 arousal vigilance) randomly presented trials within each block. The ANTI trials had the
4
5 292 following design: Warning signal (no tone/tone) × Visual cue (invalid/no cue/valid) ×
6
7
8 293 Congruency (congruent/incongruent). The 16 executive vigilance trials per block were
9
10 294 randomly selected from any possible combination of the ANTI trials design.
11
12
13

14 295 **2.5. Statistical Analyses**

15
16 296 Data analyses were conducted using RStudio [2021.09.1 Build 372](#) (RStudio Team,
17
18 297 2021) in R (R Core Team, 2021). Behavioral data figures were done with Matplotlib (Hunter,
19
20 298 2007). EEG data figures were performed using ggplot2 (Wickham, 2016), purrr (Henry &
21
22 299 Wickham, 2020), Rmisc (Hope, 2013), and magrittr (Bache & Wickham, 2020) packages in
23
24 300 RStudio for ERPs' plots and MNE-Python code (Gramfort et al., 2013) for topoplots.
25
26
27
28

29 301 Analysis of variance (ANOVA) were conducted with the afex package (Singmann et
30
31 302 al., 2021) and planned contrasts were performed with the emmeans package (Lenth, 2021).
32
33 303 Effect sizes and the 95% confidence intervals around them for planned contrasts were
34
35 304 computed with the effectsize package (Ben-Shachar et al., 2020).
36
37
38

39 305 **2.5.1. Behavioral data.**

40
41 306 Analyses were conducted following the standard analyses of the ANTI-Vea task
42
43 307 (Luna, Barttfeld, et al., 2021), [as detailed below](#). Given that three participants did not
44
45 308 complete the second session and one participant was excluded due to an extreme percentage
46
47 309 of errors on the ANTI trials (3 *SD* above the group mean), the final sample included 36
48
49 310 participants (which is indeed a larger sample size than the minimum sample size estimated by
50
51 311 power analyses, as detailed above in the 'Participants' section).
52
53
54
55

56 312 Main effects and interactions of the classic attentional functions were analyzed in the
57
58 313 ANTI trials. In these trials, those with incorrect responses (3.48 %) or with RT below 200 ms
59
60

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2
3 314 or above 1500 ms (1.35 %) were excluded from RT analysis. Two repeated-measures
4
5 315 ANOVAs were separately conducted, with RT or percentage of errors as dependent variable
6
7 316 and including warning signal (no tone/tone), visual cue (invalid/no cue/valid), and
8
9 317 congruency (congruent/incongruent) as within-participant factors.

10
11
12
13 318 In executive vigilance trials, data were collapsed across warning signal, visual cue,
14
15 319 and congruency conditions, following the standard analysis of the ANTI-Vea (Luna,
16
17 320 Barttfeld, et al., 2021). Overall executive vigilance performance was described as hits (i.e.,
18
19 321 correct responses) and misses (i.e., incorrect responses) in executive vigilance trials.
20
21
22 322 Following the standard scores computed for the Psychomotor Vigilance Test (Basner &
23
24 323 Dinges, 2011), overall arousal vigilance performance was described as fastest and slowest
25
26 324 responses in arousal vigilance trials as the first and the fifth quintile on RT, respectively. To
27
28 325 avoid including trials with RT equal to 0 ms (i.e., ‘no responses’) in the first quintile, ‘no
29
30 326 responses’ in AV trials (0.36% of AV trials) were excluded from all arousal vigilance data
31
32
33 327 analyses. Then, to analyze the executive and arousal vigilance decrements across time-on-
34
35 328 task, data were computed as a function of blocks of trials. Executive vigilance decrement was
36
37 329 analyzed with a repeated-measures ANOVA, with hits as dependent variable and including
38
39 330 blocks (seven levels) as a within-participant factor. Arousal vigilance decrement was
40
41 331 analyzed with a repeated-measures ANOVA, with mean RT in arousal vigilance trials as
42
43 332 dependent variable and blocks (seven levels) as a within-participant factor.

44
45
46
47
48 333 Partial eta-squared (η_p^2) and 95% confidence intervals around them (Cumming, 2014)
49
50 334 are reported as measure of the ANOVAs’ effect size (Kelley & Preacher, 2012). If the
51
52 335 sphericity assumption was violated (i.e., Mauchly’s test $p < .05$), degrees of freedom are
53
54 336 reported with Greenhouse-Geisser correction. To determine the significance of the linear
55
56 337 executive/arousal vigilance decrement across blocks, planned comparisons of the polynomial
57
58 338 linear component were performed.

339 2.5.2. EEG data.

340 Analyses were separately conducted for attention and vigilance components. ERPs of
341 interest were examined based on previous research on attentional networks and vigilance, as
342 detailed below. All analyses were performed on baseline corrected epochs, using the 200 ms
343 signal preceding the locking stimuli as the baseline. Early components (P1, N1, P2, and N2)
344 were analyzed measuring peak amplitude and late components (CNV, P3, and SP) measuring
345 adaptive mean amplitude as dependent variable, respectively. In all ERPs analyses, Cohens' *d*
346 (for *t* tests) or partial eta-squared (η_p^2 ; for ANOVAs) are reported as effect size score, with
347 95% confidence intervals around them (Cumming, 2014; Kelley & Preacher, 2012).

348 Independence and interactions among the classical attentional networks components
349 were analyzed following the ERPs reported by Abundis-Gutiérrez et al. (2014), who assessed
350 phasic alertness, orienting, and executive control with the ANTI task. Note that ERPs were
351 examined on the same set of trials in which mean correct RT performance was analyzed (see
352 above the 'Behavioral data' section for details). Epochs were warning signal-locked (from
353 200 ms before to 800 ms after) or target-locked (from 200 ms before to 1000 ms after).

354 Independence of attentional networks components was analyzed by means of paired *t* tests, as
355 follows. For phasic alertness, no tone vs. tone conditions were contrasted for warning signal-
356 locked N1 (230-300 ms), P2 (300-400 ms), and CNV (400-600 ms) at Fcz. For the orienting
357 network, invalid vs. valid conditions were contrasted for target-locked P1 and N1 (100-230
358 ms) at the average of Oz, O1, and O2 channels, and P3 (350-650 ms) was analyzed at the
359 average of Pz and CPz channels. **Given the short stimuli onset asynchrony (100 ms) between
360 visual cue and target stimuli, we cannot interpret ERPs of interest for the orienting network as
361 changes in EEG signal evoked by the target, especially for P1 and N1 components.**

362 **Therefore, target-locked contrasts of interest for the orienting network were plotted and
363 interpreted as a function of the difference wave between validity conditions in the time**

1
2
3 364 window of each ERP of interest (Zani & Proverbio, 2017). For the executive control network,
4
5 365 given that the Fcz channel analyzed in Abundis-Gutiérrez et al. showed a high-artifact signal
6
7 366 in our data and the N2 component could not be observed in this channel (as well as in the
8
9 367 surrounding channels to Fcz), congruent vs. incongruent conditions were contrasted for
10
11 368 target-locked N2 (250-400 ms) as closest at possible to Fcz, i.e., at CPz and adjacent channels
12
13 369 (i.e., one posterior and one anterior to CPz), and SP (500-800 ms) at Pz. The modulations of
14
15 370 phasic alertness (no tone/tone) or orienting (invalid/valid) on the executive control network
16
17 371 (congruent/incongruent) were analyzed by separated repeated-measures ANOVAs, for target-
18
19 372 locked N2 (250-400 ms) at CPz and adjacent channels and SP (500-800 ms) at Pz.
20
21 373 Importantly, as control of the potential effects induced by visual cue stimuli in the orienting
22
23 374 and orienting by congruency contrasts, Supplementary Figures 1 and 2 depict EEG signal in
24
25 375 the no cue condition along with invalid/valid conditions of cueing. Note that, critically, Supp.
26
27 376 Fig. 1 and 2 show a similar baseline for no cue and invalid/valid conditions, and in Supp. Fig.
28
29 377 2, N2 is observed in the same time window for no cue and valid/invalid conditions.
30
31
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35

36 378 ERPs associated with vigilance components were analyzed following two approaches:
37
38 379 (a) as a function of overall performance and (b) as a function of performance across time-on-
39
40 380 task. To increase the number of trials in analyses of ERPs as a function of time-on-task, first
41
42 381 and second blocks and the sixth and seventh blocks were collapsed as the initial and last
43
44 382 period, respectively. For executive vigilance, ERPs of overall responses were compared as a
45
46 383 function of hits or misses in executive vigilance trials and ERPs across time-on-task were
47
48 384 analyzed as a function of hits in the initial and last period of the task. Epochs were target-
49
50 385 locked (from 200 ms before to 1000 ms after) in executive vigilance trials and ERPs were
51
52 386 analyzed by paired *t* tests in components and channels based on previous research with
53
54 387 signal-detection tasks (Bonnefond et al., 2010; Groot et al., 2021; Lara et al., 2018;
55
56 388 McMackin et al., 2020; Reteig et al., 2019), in particular: P1 (100-200 ms), N1 (140-230 ms),
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1
2
3 389 and P3 (350-650 ms) at Pz and SP (500-800 ms) at Cz and adjacent channels. Note that,
4
5 390 given that clear peaks were not observed in P1 and N1 in executive vigilance contrasts, all
6
7 391 ERPs in executive vigilance contrasts were analyzed as a function of adaptive mean
8
9 392 amplitude (Martín-Arévalo et al., 2015).

10
11
12
13 393 For arousal vigilance, ERPs of overall responses were compared as a function of the
14
15 394 fastest and slowest RT in arousal vigilance trials (Basner & Dinges, 2011) and ERPs across
16
17 395 time-on-task were analyzed as a function of responses in arousal vigilance trials of the first
18
19 396 and the last period of the task. Epochs were target-locked (from 200 ms before to 1000 ms
20
21 397 after) on arousal vigilance trials and ERPs were analyzed by paired *t* tests in components and
22
23 398 channels based on previous research with single RT tasks (Hoedlmoser et al., 2011), in
24
25 399 particular: N1 (200-300 ms) and P2 (350-650 ms) in Oz, O1, and O2 channels.

30 400 3. Results

31 401 3.1. Behavioral performance

32 402 3.1.1. Phasic alertness, orienting, and executive control

33
34 403 All typical main effects usually observed with the ANTI (Callejas et al., 2004) and
35
36 404 ANTI-Vea (Luna et al., 2018; Luna, Roca, et al., 2021) tasks were observed as significant
37
38 405 here (see Fig. 2). For warning signal {RT: [$F(1, 35) = 109.61, p < .001, \eta_p^2 = .76, 95\% \text{ CI}$
39
40 406 (.60, .84)]; errors: [$F(1, 35) = 15.94, p < .001, \eta_p^2 = .31, (.08, .52)$]}, responses were faster
41
42 407 and more precise in the tone than in the no tone condition. The visual cue main effect {RT: [F
43
44 408 (1.98, 69.27) = 79.22, $p < .001, \eta_p^2 = .69, (.57, .77)$]; errors: [$F(1.90, 66.43) = 3.39, p = .042,$
45
46 409 $\eta_p^2 = .09, (.00, .23)$] } showed the typical validity {invalid > valid: only for RT [$t(35) = 12.12,$
47
48 410 $p < .001, d = 2.05, 95\% \text{ CI}(1.46, 2.63)$]; not for errors: [$t(35) = -1.67, p = .232, d = -0.28, (-$
49
50 411 0.62, 0.06)]}, benefits {no cue > valid: RT [$t(35) = 7.62, p < .001, d = 1.29, (0.84, 1.73)$];

412 although reversed for errors: [$t(35) = -2.60, p = .035, d = -0.44, (-0.78, -0.09)$]} and costs
 413 {invalid > no cue: only for RT [$t(35) = 4.91, p < .001, d = 0.83, (0.44, 1.21)$]; not for errors:
 414 [$t(35) = 0.73, p = .748, d = 0.12, (-0.21, 0.45)$]} effects. For congruency {only for RT: [$F(1,$
 415 $35) = 106.85, p < .001, \eta_p^2 = .75, (.60, .84)$]; not for errors: [$F(1, 35) = 0.03, p = .853, \eta_p^2 <$
 416 $.01, (.00, .09)$]}, responses were faster in the congruent than incongruent condition.

417 *Please, insert Figure 2 here.*

418 The two-way interactions usually observed with the ANTI (Callejas et al., 2004) and
 419 the ANTI-Vea (Luna et al., 2018; Luna, Roca, et al., 2021) were observed as significant only
 420 for RT as dependent variable (see Table 2): Warning signal \times Visual cue {RT: [$F(1.87,$
 421 $65.43) = 60.27, p < .001, \eta_p^2 = .63, (.49, .73)$]; errors: [$F(1.73, 60.48) = 0.78, p = .445, \eta_p^2 =$
 422 $.02, (.00, .11)$]}, Warning signal \times Congruency {RT: [$F(1, 35) = 20.64, p < .001, \eta_p^2 = .37,$
 423 $(.13, .57)$]; errors: [$F(1, 35) = 0.90, p = .350, \eta_p^2 = .03, (.00, .20)$]}, and Visual cue \times
 424 Congruency {RT: [$F(1.90, 66.34) = 5.33, p = .008, \eta_p^2 = .13, (.01, .28)$]; errors: [$F(1.97,$
 425 $68.86) = 0.26, p = .765, \eta_p^2 < .01, (.00, .07)$]}.
 426

426 *Please, insert Table 2 here.*

427 3.1.2. Executive and arousal vigilance.

428 As usually observed with the ANTI-Vea (Luna et al., 2018; Luna, Roca, et al., 2021),
 429 the executive vigilance decrement was observed as a significant decrease in hits across blocks
 430 [$F(4.64, 162.43) = 9.05, p < .001, \eta_p^2 = .21, (.10, .28)$] with a significant linear component [t
 431 $(35) = -5.14, p < .001, \eta_p^2 = .43, (.22, 1.00)$] (see Fig. 3). Unexpectedly, however, the arousal
 432 vigilance decrement was not observed: the main effect of mean RT across blocks was not
 433 significant [$F(3.93, 137.49) = 0.45, p = .769, \eta_p^2 = .01, (.00, .02)$] (see also Fig. 3).

434 *Please, insert Figure 3 here.*

435 Overall performance of vigilance components is reported in Table 3.

436 *Please, insert Table 3 here.*

437 **3.2. Event-related potentials**

438 **3.2.1. Phasic alertness, orienting, and executive control**

439 ERPs similar to those observed by Abundis-Gutiérrez et al. (2014) were found for the
 440 classic attentional networks components. For phasic alertness, significant and relatively large
 441 differences were observed between tone and no tone conditions in N1 [$t(35) = -8.14, p <$
 442 $.001, d = -1.36, (-1.83, -0.91)$], P2 [$t(35) = 9.07, p < .001, d = 1.51, (1.04, 2.02)$], and CNV [t
 443 $(35) = -4.91, p < .001, d = -0.82, (-1.21, -0.44)$] components for warning-signal locked
 444 contrasts at FCz (see Fig. 4).

445 *Please, insert Figure 4 here.*

446 For the orienting network, there were no significant differences between cueing
 447 validity conditions in the time windows of P1 [$t(35) = 0.07, p = .941, d = -0.01, (-0.34,$
 448 $0.32)$] and N1 [$t(35) = -1.17, p = .251, d = -0.19, (-0.53, 0.14)$] components at occipital
 449 channels, as depicted by the flat difference wave in Fig. 4. Similarly, no significant
 450 differences were observed in the time window of P3 component at CPz and Pz, [$t(35) = 1.30,$
 451 $p = .201, d = 0.22, (-0.12, 0.55)$], as shown by the flat difference wave between the invalid
 452 and valid cue conditions in the same Fig 4.

453 Lastly, for the executive control network, significant differences were observed
 454 between congruency conditions in N2 at CPz and adjacent channels [$t(35) = 2.20, p = .034, d$
 455 $= 0.37, (0.03, 0.71)$] and SP at Pz [$t(35) = 3.27, p = .002, d = 0.54, (0.19, 0.90)$] target-locked
 456 contrasts (see Fig. 5).

457 *Please, insert Figure 5 here.*

458 Regarding the modulations among the classic attentional networks, SP at Pz for
 459 executive control was not modulated by phasic alertness [$F(1, 35) = 0.26, p = .612, \eta_p^2 < .01,$

1
2
3 460 (.00, .15)] nor attentional orienting [$F(1, 35) = 0.75, p = .391, \eta_p^2 = .02, (.00, .19)$] conditions.
4
5
6 461 However, N2 at CPz and adjacent channels for executive control was significantly modulated
7
8 462 although only by attentional orienting [$F(1, 35) = 5.80, p = .021, \eta_p^2 = .14, (.00, .36)$] (see Fig.
9
10 463 5), not by phasic alertness [$F(1, 35) = 0.27, p = .604, \eta_p^2 < .01, (.00, .15)$]. **Opposite differences**
11
12
13 464 **between congruent and incongruent conditions were observed for valid and invalid conditions,**
14
15 465 **although pairwise comparisons showed that no N2 difference was significant: valid cue [$t(35)$**
16
17 466 **= -1.94, $p = .061, d = -0.33, (-0.67, 0.01)$] and invalid cue [$t(35) = 1.67, p = .104, d = 0.28, (-$**
18
19 467 **0.06, 0.62)].**

468 3.2.2. Executive vigilance.

469 As can be observed in Fig. 6, contrasts between overall hits and misses showed a
26
27
28 470 significant (although **with a relatively small effect size**) larger amplitude in P1 in hits than
29
30 471 misses, [$t(35) = 2.28, p = .029, d = 0.38, (0.04, 0.73)$], but **there were no** significant
31
32 472 differences in N1 [$t(35) = 0.58, p = .560, d = 0.10, (-0.23, 0.43)$] and P3 [$t(35) = -0.62, p =$
33
34 473 **.538, $d = -0.10, (-0.44, 0.23)$] components in Pz. The SP component **did not show a**
35
36 474 **significant** difference between hits and misses in Cz and adjacent channels, [$t(35) = 2.01, p =$
37
38 475 **.052, $d = 0.34, (0.00, 0.68)$].****

476 *Please, insert Figure 6 here.*

477 Importantly, as depicted in Fig. 6, the decrement in hits was accompanied by a
45
46 478 significant change in ERPs amplitude across time-on-task. Regarding early ERPs in Pz,
47
48 479 analysis on pre-defined time windows showed no significant change in both P1 [$t(35) = 1.08,$
49
50 480 $p = .286, d = 0.18, (-0.15, 0.52)$] and N1 [$t(35) = 1.14, p = .258, d = 0.19, (-0.14, 0.53)$]
51
52 481 amplitude across task periods. However, the pattern depicted in Fig. 6 shows significant
53
54 482 differences across task periods in N1. A-posteriori analysis in a narrow time window (180-
55
56 483 210 ms) close to N1 peak confirmed **a relatively small and significant** decrease in N1
57
58 484 amplitude across task period [$t(35) = 2.34, p = .025, d = 0.39, (0.05, 0.74)$]. In addition,

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3 485 significant increases in both P3 at Pz [$t(35) = 2.14, p = .039, d = 0.36, (0.02, 0.70)$] and SP at
4
5 486 Cz and adjacent channels [$t(35) = 3.44, p = .002, d = 0.57, (0.22, 0.94)$] were observed
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7
8 487 between the first and the last period of the task.
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10 488 3.2.3. Arousal vigilance.

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12
13 489 Significant differences in ERPs among trials with fastest and slowest arousal vigilance
14
15
16 490 responses were observed in occipital channels of interest (see Fig. 7). In particular, N1
17
18 491 showed a smaller amplitude for the slowest than for the fastest responses, but only in O1 [t
19
20 492 (35) = 2.50, $p = .017, d = 0.42, (0.07, 0.76)$]; the difference was clearly not significant in Oz
21
22 493 [$t(35) = 1.68, p = .101, d = 0.28, (-0.06, 0.62)$] and O2 [$t(35) = 0.64, p = .528, d = 0.11, (-$
23
24 494 $0.23, 0.44)$]. Regarding P2, peak amplitude was significantly smaller for the slowest than for
25
26 495 the fastest responses in all occipital channels of interest: O1 [$t(35) = -3.57, p = .001, d = -$
27
28 496 $0.59, (-0.96, -0.24)$], Oz [$t(35) = -2.86, p = .007, d = -0.48, (-0.83, -0.13)$], and O2 [$t(35) = -$
29
30 497 $2.83, p = .008, d = -0.47, (-0.82, -0.13)$].
31
32
33
34

35 498 *Please, insert Figure 7 here.*

36 499 Lastly, for arousal vigilance, no significant changes in ERPs of interest were observed
37
38
39 500 as a function of task period, in agreement with the lack of behavioral arousal vigilance
40
41 501 decrement in mean RT. N1 amplitude was not significantly different between the first and
42
43 502 last task period in O1 [$t(35) = 0.92, p = .364, d = 0.15, (-0.18, 0.49)$], Oz [$t(35) = 1.63, p =$
44
45 503 $.113, d = 0.27, (-0.06, 0.61)$], and O2 [$t(35) = 1.62, p = .115, d = 0.27, (-0.07, 0.61)$].
46
47
48 504 Similarly, for P2, no significant changes between the first and last task period were observed
49
50 505 in O1 [$t(35) = -0.37, p = .714, d = -0.06, (-0.39, 0.27)$], Oz [$t(35) = -0.63, p = .524, d = -$
51
52 506 $0.11, (-0.44, 0.22)$], and O2 [$t(35) = -0.70, p = .488, d = -0.12, (-0.45, 0.21)$].
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4. Discussion

The present study aimed at further [examining the ERPs associated with](#) the attentional networks system (S. E. Petersen & Posner, 2012; Posner et al., 2006; Posner, 2012; Posner & Petersen, 1990). Most of the previous studies on ERPs with attentional networks tasks like the ANT or the ANTI focused on phasic alertness, attentional orienting, and executive control functions (Abundis-Gutiérrez et al., 2014; Galvao-Carmona et al., 2014; Gonçalves et al., 2018; Neuhaus et al., 2010; Zani & Proverbio, 2017). In contrast, ERPs associated with vigilance components have been observed using different paradigms, by measuring vigilance via signal-detection (Bonnefond et al., 2010; Lara et al., 2018; Reteig et al., 2019) or RT (Hoedlmoser et al., 2011; Ramautar et al., 2013; Witkowski et al., 2015) tasks. Therefore, and critically, ERPs associated with vigilance components were previously measured in different contexts and with different task sets, with participants likely in different attentional states. In the present study, importantly, attentional and vigilance ERPs were simultaneously examined using the newest version of the ANT, the ANTI-Vea (Luna et al., 2018). This task [assesses](#) the independence and interactions of the classic attentional networks components while measuring the executive and arousal vigilance decrements across time-on-task. Thus, by measuring high-density EEG signal while participants completed the ANTI-Vea in two repeated sessions, we reported critical evidence about ERPs associated with the classic attentional components and for executive and arousal vigilance, when both components are measured under the same context and attentional state of participants.

ERPs previously observed by Abundis-Gutiérrez et al. (2014) for the classic attentional components were replicated in the present study. For phasic alertness, warning signal reduced RT and elicited early attentional preparation ERPs as N1 and P2 (Jonkman, 2006) as well as CNV as an anticipatory component to the target in central-frontal regions (Abundis-Gutiérrez et al., 2014). [It should be noted that N1 and P2 might be more associated](#)

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3 532 with the salience of the auditory tone than with changes in the phasic alertness state.
4
5 533 However, and importantly, the CNV has been proposed as a marker of readiness for an
6
7 534 incoming target, a component elicited both by visual (Galvao Carmona et al., 2014) and
8
9 535 auditory (Abundis-Gutiérrez et al., 2014) warning signals. Galvao-Carmona et al. (2014)
10
11 536 observed that CNV's amplitude increases as a function of the information provided by the
12
13 537 anticipatory signal. Using a modified version of the ANT, Galvao-Carmona et al. observed
14
15 538 that CNV was larger when the target was anticipated by a 100% predictive visual spatial cue
16
17 539 –for measuring attentional orienting– than by a not predictive visual central cue –for
18
19 540 measuring phasic alertness–. Note that, however, in Galvao-Carmona et al. the stimuli onset
20
21 541 asynchrony between visual cues and the target was larger (1000 ms) than in the present study
22
23 542 (500 ms between tone and target), which could increase preparation for response stimuli in
24
25 543 both visual cue conditions. Moreover, it has been proposed that while auditory signals are
26
27 544 more effective than visual cues to increase phasic alertness (Fernandez-Duque & Posner,
28
29 545 1997; A. Petersen et al., 2017), cueing validity paradigms are more effective than 100%
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31 546 predictive cues for measuring orienting (Posner, 2016). Thus, as observed in the present
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33 547 study, probably the CNV is probably more associated with phasic alertness changes elicited
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35 548 by warning signals (either informative or not) that increase temporal preparation for target
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37 549 incoming (Pauletti et al., 2014) than with orienting mechanisms anticipating target
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39 550 localization (Galvao-Carmona et al., 2014).

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42 551 Regarding the orienting network, visual spatial cues did not modulate early sensory
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44 552 processing in occipital regions, showing a similar signal for valid and invalid conditions in
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46 553 time window for P1 and N1 components. Previous studies with the ANT have shown
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48 554 increased target-locked N1 when spatial cues are 100% predictive about target localization
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50 555 (Gonçalves et al., 2018; Neuhaus et al., 2010). It has been reported that when exogenous cues
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52 556 reorient attention to lateralized targets, cueing validity modulates P1 and N1 (Fu et al., 2001,
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3 557 2005; Talsma et al., 2007). In the present study, however, exogenous cues anticipated target
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5 558 localization at central positions (up/down), which might have reduced validity effects in early
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7 559 perceptual target detection, as documented in Abundis-Gutiérrez et al. (2014). Note that
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9 560 cueing validity neither modulated late target processing in central-parietal regions, as signal
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11 561 was similar in the time window for P3 in invalid and valid cueing conditions (Correa et al.,
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13 562 2006; Randall & Smith, 2011; Talsma et al., 2007). Previous research has observed an
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15 563 increase in P3 after invalid cueing, which has been explained as the cost of disengaging and
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17 564 reorienting attention (Abundis-Gutiérrez et al., 2014), as well as a mechanism for inhibiting
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19 565 the representation of a planned movement and activating a newly demanded response
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21 566 (Randall & Smith, 2011).

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27 567 Importantly, it must be noted that, in the ANTI-Vea, the stimulus onset asynchrony
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29 568 between visual cues and target is relatively short (100 ms), which limits the interpretation
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31 569 about ERPs associated with the orienting effect as changes evoked by the target stimuli.
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33 570 Considering this limitation, ERPs associated with the orienting network were not interpreted
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35 571 as evoked by the target stimuli and were instead discussed as signal modulation by the
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37 572 validity condition in the time window of each ERP of interest. Note that, however, the effect
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39 573 of visual cue on ERPs of interest seems to be relatively small, as demonstrated by the similar
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41 574 baseline between no cue and invalid/valid conditions observed in Supp. Fig. 1 and 2. Future
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43 575 ERP' studies with the ANTI-Vea should consider this critical aspect of the task when
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45 576 interpreting outcomes associated with cueing validity.

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49 577 For the executive control network, flankers' interference reduced N2 and increased SP
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51 578 amplitudes, as reported in Abundis-Gutiérrez et al. (2014). Although previous studies with
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53 579 the ANT observed P3 as a cognitive control component involved in late target processing
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55 580 (Galvao-Carmona et al., 2014; Gonçalves et al., 2018; Neuhaus et al., 2010), Abundis-
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57 581 Gutiérrez et al. proposed the N2 component for conflict detection and the SP component for
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3 582 post-conflict resolution as executive control mechanisms. Previous research has extensively
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5 583 associated N2 with conflict detection and response inhibition mechanisms (Folstein & Van
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7 584 Petten, 2008; Swainson et al., 2003). Indeed, while some visual paradigms might elicit N2 in
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9 585 the posterior scalp –as in the present study–, auditory paradigms seem to especially evoke N2
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11 586 in rather frontal scalp, having as source region the anterior cingulate cortex (Folstein & Van
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13 587 Petten, 2008), i.e., a cortex strongly associated with conflict detection (Botvinick et al., 2001,
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15 588 2004; Yeung et al., 2004). Further research supports N2 as a key component in executive
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17 589 control: while increased N2 latency and reduced N2 amplitude were associated with cognitive
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19 590 control loss across aging (Kropotov et al., 2016), transcutaneous vagus nerve stimulation has
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21 591 shown to improve sequential conflict adaptation by reducing N2 amplitude (Fischer et al.,
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23 592 2018). Regarding SP, also known as error positivity, evidence suggests that this component
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25 593 appears 200-400 ms after responses and that it is associated with error resolution
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27 594 independently of conflict and stimuli modality (West, 2003; West & Moore, 2005). The
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29 595 increase in SP was associated with error commission awareness in cognitive control tasks
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31 596 (Endrass et al., 2012) as well as cognitive control decline across aging (Larson et al., 2016).
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33 597 Altogether, the present and previous findings support N2 and SP as two key components of
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35 598 the executive control network (Posner, 2012; Posner et al., 2006).

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43 599 Importantly, contrary to Abundis-Gutiérrez et al. (2014), executive control N2
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45 600 component was modulated by the orienting network. Previous research has shown that N2 is
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47 601 likely to be modulated by temporal orienting of attention, as invalid cues increase N2
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49 602 amplitude impairing conflict detection (Correa et al., 2006). *In our study, the N2 effect (i.e.,*
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51 603 *more negative for incongruent than congruent) was only observed for invalid trials, being*
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53 604 *reversed for valid ones, although pairwise comparisons showed that no effect reached*
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55 605 *significance, limiting the interpretation of this outcome.* In a study conducted with the ANT,
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57 606 Zani & Proverbio (2017) observed modulations of attentional orienting over SP component of
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3 607 the executive control network. Nevertheless, as previously discussed, while in the ANT the
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5 608 spatial cue is 100% predictive about target localization, the cueing validity paradigm
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7 609 embedded in the ANTI and ANTI-Vea has benefits and cost effects in target localization
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9 610 beyond the automatic orienting of attention (Callejas et al., 2004, 2005; Posner, 2016).
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11 611 Notably, although the attentional networks model anticipates neural interactions among the
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13 612 networks (S. E. Petersen & Posner, 2012; Posner & Petersen, 1990), in the present study N2
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15 613 modulation by the orienting network was the only interaction observed. While the present
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17 614 outcomes do not fully support the attentional networks interactions usually derived from
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19 615 behavioral data, it should be noted that evidence on ERPs with the ANTI task –which
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21 616 combines auditory warning signal and cueing validity paradigm anticipating response’
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23 617 stimuli– is still considerably scarce. Further research is, therefore, necessary to better
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25 618 understand potential interactions among classic attentional functions in ERPs components.
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31 619 Regarding vigilance components, different ERPs were observed in the same task
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33 620 period for executive and arousal vigilance. To the best of our knowledge, this is the first
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35 621 study in analyzing ERPs associated with executive and arousal vigilance with independent
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37 622 measures and within a single session. Previously, Galvao-Carmona et al. (2014) observed in
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39 623 the no cue condition of the ANT a slow CNV prior to the target, which was interpreted as a
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41 624 general level of tonic alerting. Notwithstanding, the no cue condition in the ANT is not a
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43 625 direct measure of vigilance (Ishigami & Klein, 2010; Roca et al., 2011), which limits the
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45 626 analysis of a clear ERP associated with vigilance functioning. Instead, in the ANTI-Vea, both
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47 627 executive vigilance –measured in the signal-detection subtask– and arousal vigilance –
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49 628 measured in the RT subtask– are independently assessed (Luna et al., 2018; Luna, Barttfeld,
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51 629 et al., 2021; Luna, Roca, et al., 2021). Although the hits/misses rate and hits decrease across
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53 630 time-on-task for executive vigilance were similar to previous studies with the ANTI-Vea, the
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55 631 arousal vigilance decrement in mean RT was not observed here (Luna, Roca, et al., 2021). A
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3 632 similar pattern was previously found in Luna et al. (2020), wherein participants completed
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5 633 the ANTI-Vea while anodal/sham transcranial direct current stimulation was delivered and
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7 634 EEG signal was recorded. Indeed, although we did not plan to analyze ERPs of arousal
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9 635 vigilance as a function of RT variability, in the present study the arousal vigilance decrement
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11 636 was also not observed for *SD* of RT across blocks, [$F(1, 35) = 0.60, p = .658, \eta_p^2 = .02, (.00,$
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13 637 $.03)$]. Although the absence of behavioral arousal vigilance decrement could be a limitation
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15 638 for analyzing ERPs associated with changes across time-on-task in this component, we
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17 639 observed other typical measures for arousal vigilance that are usually reported in single RT
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19 640 tasks, i.e., as the fastest and slowest RT (Basner & Dinges, 2011; Molina et al., 2019).
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21 641 Therefore, in summary, in the present study executive and arousal vigilance could be
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23 642 independently measured while assessing the classic attentional networks with the ANTI-Vea
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25 643 (Luna et al., 2018).

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27 644 Similar ERPs as those reported in previous studies with signal-detection tasks were
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29 645 observed for executive vigilance (Boksem et al., 2005; Bonnefond et al., 2010; Lara et al.,
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31 646 2018; Reteig et al., 2019). Early sensory processing components showed larger P1 amplitude
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33 647 for hits than misses, which might be associated with the correct visual detection of infrequent
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35 648 targets in the behavioral responses (Reteig et al., 2019). Previous studies have also observed
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37 649 P1 as a component associated with correct detection of infrequent targets (Boksem et al.,
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39 650 2005; Groot et al., 2021). Most importantly, the executive vigilance decrement in hits was
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41 651 accompanied with a decrease in N1 and an increase in late ERPs amplitude, i.e., P3 and SP,
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43 652 across time-on-task. Previous evidence was scarce and inconsistent regarding ERPs
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45 653 associated with the executive vigilance decrement in signal-detection tasks, as either
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47 654 increased (Lara et al., 2018), decreased (Boksem et al., 2005), or similar (Reteig et al., 2019)
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49 655 N1 across time-on-task has been reported. Moreover, for late ERPs, while in Lara et al.
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51 656 (2018) P3 decreased across time-on-task, Bonnefond et al. (2010) found instead late P1
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3 657 increase across blocks. As commented by Abundis-Gutiérrez et al. (2014), the fact that SP
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5 658 has been observed either before, during, or after the motor response might indicate that this
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7 659 component is associated with post-target processing rather than with motor preparation. Late
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9 660 ERPs changes across time-on-task have received opposite interpretations by attentional
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11 661 resources theories: while amplitude decrease was proposed as a marker of resource depletion
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13 662 with time-on-task (Lara et al., 2018; Warm et al., 2008), amplitude increase was instead
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15 663 discussed as an increase in effort to keep resource allocation on the external task (Bonnefond
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17 664 et al., 2010; Koelega et al., 1992).

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22 665 Nowadays, there is an open debate regarding what ‘attentional resources’ are at the
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24 666 neural level and which neural markers might be indicating a change in resources disposition
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26 667 as a function of time-on-task (Neigel et al., 2020; Thomson et al., 2016). Although the
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28 668 present outcomes follow those observed by Bonnefond et al. (2011), we recognize that
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30 669 further research is still necessary to elucidate whether P3 and SP increase across time-on-task
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32 670 can be associated to an increase in both effort and resources allocation in the external task
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34 671 with time-on-task in executive vigilance. To further understand the implications of neural
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36 672 changes in the vigilance decrement phenomenon, future research should also examine
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38 673 whether changes in ERPs across time-on-task can be associated with changes in sensitivity
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40 674 and/or response bias (Mazzi et al., 2020). In the present study, the decrease in hits was
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42 675 accompanied by a decrease in false alarms [$F(3.37, 117.82) = 3.90, p = .008, \eta_p^2 = .10, (.02,$
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44 676 $.16)$], which led to a loss in sensitivity [$F(4.51, 157.91) = 3.47, p = .007, \eta_p^2 = .09, (.01, .15)$]
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46 677 as well as a change in response bias towards a more conservative criterion [$F(4.10, 143.49) =$
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48 678 $5.69, p < .001, \eta_p^2 = .14, (.05, .21)$]. Future studies aiming at determining ERPs specifically
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50 679 associated with sensitivity or response bias might modulate response bias by instructing
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52 680 participants towards a more conservative criterion, as in Mazzi et al. (2020), or reduce the
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54 681 perceptual salience of the infrequent target to modulate the loss in sensitivity.

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3 682 Lastly, for arousal vigilance, while no significant change across time-on-task was
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5 683 observed in mean RT and early ERPs, N1 and P2 in occipital channels were larger for fastest
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7 684 than slowest arousal vigilance responses. Fastest and slowest RT are two of the most used
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9 685 scores to assess arousal vigilance states with the Psychomotor Vigilance Test (Basner &
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11 686 Dinges, 2011). Previous researches have demonstrated that BOLD signal (Drummond et al.,
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13 687 2005) and theta, alpha, and beta power (Molina et al., 2019) also change as a function of the
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15 688 speed of responses in the Psychomotor Vigilance Test. Importantly, the present outcomes are
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17 689 in the same vein as those observed by Hoedlmoser et al. (2011), who observed a decrease in
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19 690 early ERPs amplitude after a night of sleep deprivation and measured arousal vigilance with
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21 691 the Psychomotor Vigilance Test. Compared to this study, ERPs reported in Hoedlmoser et al.
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23 692 were closer to target onset, probably because the millisecond counter was the only stimuli
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25 693 expected, while in the present study participants were completing three simultaneous
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27 694 subtasks, all with different target stimuli. While previous research found ERPs changes
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29 695 associated with arousal vigilance loss in repeated sessions during a night (Hoedlmoser et al.,
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31 696 2011; Ramautar et al., 2013) or even weeks (Witkowski et al., 2015), we observed ERPs
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33 697 changes related to arousal vigilance loss (i.e., fastest vs. slowest responses) within a single
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35 698 session of ~32 min.

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43 699 Interestingly, different ERPs changes were observed for executive and arousal
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45 700 vigilance. While the executive vigilance decrement seems to be more associated with
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47 701 amplitude increase in late ERPs (i.e., P3 and SP), arousal vigilance loss was particularly
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49 702 related to amplitude decrease in early ERPs (i.e., N1 and P2). Altogether, the present
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51 703 outcomes provide novel and further evidence on the different neural basis of vigilance
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53 704 components (Luna et al., 2020; Sanchis et al., 2020), further supporting executive and arousal
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55 705 vigilance as two independent components of the attentional networks system (S. E. Petersen
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57 706 & Posner, 2012; Posner & Petersen, 1990).

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3 707 To conclude, the present study provides novel and critical evidence showing that
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5 708 ERPs associated with attentional and vigilance components can be simultaneously observed
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7 709 within a single session, [supporting different](#) functional neural mechanisms underlying the
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9 710 attentional networks system (S. E. Petersen & Posner, 2012). Regarding the classic
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11 711 attentional functions, similar ERPs to those previously observed by Abundis-Gutiérrez et al.
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13 712 (2014) were found here, in particular: (a) for phasic alertness, warning signal elicited early
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15 713 attentional preparation N1 and P2 components as well as CNV as an anticipatory mechanism
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17 714 to target; (b) for the orienting network, cueing validity did not modulate P1 and N1 early
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19 715 sensory processing components [and, at difference to Abundis-Gutiérrez et al., cueing validity](#)
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21 716 [did not modulate P3 target processing component](#); (c) for the executive control network,
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23 717 congruency modulated conflict detection in N2 as well as conflict resolution in SP
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25 718 components. Importantly, [different](#) ERPs were simultaneously observed for executive and
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27 719 arousal vigilance. Whereas the executive vigilance decrement was accompanied by an
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29 720 increase in late ERPs (i.e., P3 and SP) amplitude, reduced arousal vigilance was [associated](#)
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31 721 with a decrease in early ERPs (i.e., N1 and P2) amplitude. Altogether, the present study
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33 722 provides novel and high-powered evidence about [specific ERPs associated with multiple](#)
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35 723 [attentional and vigilance components of](#) the attentional networks system (S. E. Petersen &
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37 724 Posner, 2012; Posner, 2012; Posner et al., 2006; Posner & Petersen, 1990).
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3 1024 **Author Note**

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18
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21 1033 Framework repository, <https://osf.io/6kc7x/>. Data supporting the conclusions of this study
22
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Tables

1040 **Table 1.** Summary of event-related potentials expected in the present study based on previous
 1041 research.

Cognitive component	ERPs expected	Previous evidence
Phasic alertness	N1, P2, and CNV	Abundis-Guitérrez et al. (2014)
Orienting	P1, N1, and P3	Abundis-Guitérrez et al. (2014)
Executive control	N2 and SP	Abundis-Guitérrez et al. (2014)
Executive vigilance	P1 and N1	Boksem et al. (2005), Groot et al. (2021), Lara et al. (2018), McMackin et al. (2020), Reteig et al. (2019)
	P3 and late positivity	Bonnefond et al. (2010), Lara et al. (2018)
Arousal Vigilance	Early ERPs (P1 and N1)	Hoedlmosser et al. (2011)

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1043 *Note.* ERP = event-related potential, CNV = contingent negative variation, SP = slow

1044 positivity.

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3 1045 **Table 2.** Mean correct RT and percentage of errors as a function warning signal, visual cue,
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5 1046 and congruency conditions.
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			Reaction time (ms)				Errors (%)			
			Congruent		Incongruent		Congruent		Incongruent	
			<i>M</i>	95% CI	<i>M</i>	95% CI	<i>M</i>	95% CI	<i>M</i>	95% CI
No tone	Invalid		630	[595, 665]	663	[630, 695]	4.02	[2.55, 5.49]	4.17	[2.77, 5.54]
	No cue		641	[608, 674]	659	[629, 690]	4.27	[2.60, 5.93]	4.07	[2.74, 5.40]
	Valid		604	[572, 636]	630	[598, 663]	5.46	[3.82, 7.09]	4.61	[2.65, 6.57]
Tone	Invalid		608	[577, 639]	657	[624, 691]	2.48	[1.62, 3.34]	2.63	[1.53, 3.72]
	No cue		582	[553, 611]	624	[595, 653]	1.88	[0.97, 2.80]	2.03	[1.16, 2.90]
	Valid		575	[545, 605]	610	[579, 641]	2.93	[1.67, 4.18]	3.17	[2.17, 4.18]

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27 1048 *Note.* *M* = mean, CI = confidence intervals, ms = milliseconds.
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1049 **Table 3.** Descriptive statistics for responses in executive and arousal vigilance subtasks.

	<i>N</i>	Min	Max	<i>M</i>	95% CI
Executive vigilance					
Hits	164.81	68	212	73.57%	[67.57, 79.58]
Misses	59.19	12	156	26.43%	[20.42, 32.43]
Arousal vigilance					
Fastest	44.89	42	45	386 ms	[362, 409]
Slowest	43.92	41	44	594 ms	[555, 632]

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1051 *Notes.* *N* = absolute frequency per participant, Min = minimum, Max = maximum, *M* = mean,

1052 CI = confidence intervals, ms = milliseconds.

1053 *N* represents the mean number of trials in which that response was observed, with its

1054 respective Min and Max across participants. *M* represents the mean performance in that

1055 score, with its respective variability (i.e., 95% CI around the mean).

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3 1056 **Figure captions**
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6 1057 **Fig. 1.** Procedure for the three types of trials of the ANTI-Vea task. Stimuli sequence and
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8 1058 timing for (a) ANTI and executive vigilance and (b) arousal vigilance trials. In (a), the left
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10 1059 panel of target and flankers represents an ANTI trial (centered target) whereas the right one
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12 1060 represents an executive vigilance trial (displaced target). (c) Examples of visual cue
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14 1061 conditions for measuring the orienting network. (d) Correct responses expected for the ANTI
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16 1062 (left), executive vigilance (middle) and arousal vigilance (right) trials. All trials lasted 4100
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18 1063 ms.; the initial and final screens had a random timing aiming at making the response' stimuli
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20 1064 appearance time unpredictable. In all trials, responses were allowed until 2000 ms.
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25 1065 **Fig. 2.** Mean correct RT (superior graphs) and percentage of errors (bottom graphs) for
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27 1066 warning signal (left panels), visual cue (center panels), and congruency (right panels)
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29 1067 conditions. Error bars represent 95% CI of the mean and were computed following the
30
31 1068 Cousineau-Morey method (Morey, 2008).
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35 1069 **Fig. 3.** Executive (left panel) and arousal (right panel) vigilance performance across blocks.
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37 1070 Error bars represent 95% CI of the mean and were computed following the Cousineau-Morey
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39 1071 method (Morey, 2008).
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42 1072 **Fig. 4.** Event-related potentials associated with (a) phasic alertness and (b) the orienting
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44 1073 network. (a) Signal amplitude as a function of warning signal condition (no tone/tone) at Fcz,
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46 1074 locked at warning signal stimuli (dashed vertical red line). Signal amplitude locked at target
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48 1075 stimuli (dashed vertical black line) as a function of cueing validity (valid/invalid, presented at
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50 1076 the dashed vertical gray line) at the average of (b) O1, Oz, and O2 channels for P1 and N1
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52 1077 components and (c) CPz and Pz channels for P3 component. In (b) and (c), the difference
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54 1078 wave represent mean difference between invalid and valid signal. Significant differences ($p <$
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56 1079 $.05$) between conditions at each time point are highlighted with a black line above the x-axis.
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3 1080 Shadowed traces around mean signal represent within-participant 95% CI of mean for that
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5 1081 condition and were computed with the Cousineau-Morey method (Morey, 2008). Topoplots
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7 1082 represent tone minus no tone signal in (a) and invalid minus valid signal in (b) and (c).
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10 1083 Channels of interest (named in each figure title) are highlighted with a yellow marker on each
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12 1084 topoplot.

15 1085 **Fig. 5.** Event-related potentials associated with the executive control network (a and b) and
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17 1086 with the executive control network modulated by the cueing validity effect (c and d). Signal
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19 1087 amplitude target-locked as a function of congruency at (a) the average of CPz and adjacent
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21 1088 channels for N2 component and (b) Pz channel for SP component. Signal amplitude target-
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23 1089 locked as a function of congruency at the average of CPz and adjacent channels for N2
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25 1090 component in (c) valid cue condition and (d) invalid cue condition. The visual cue (dashed
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27 1091 vertical gray line) is presented 50 ms before the target (dashed vertical black line). In all
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29 1092 amplitude signal plots, significant differences ($p < .05$) between conditions at each time point
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31 1093 are highlighted with a black line above the x-axis. Shadowed traces around mean signal
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33 1094 represent within-participant 95% CI of mean for that condition and were computed with the
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35 1095 Cousineau-Morey method (Morey, 2008). Topoplots represent incongruent minus congruent
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37 1096 signal in (a) and (b), and incongruent minus congruent signal in valid (c) and invalid (d)
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39 1097 trials. Channels of interest (named in each figure title) are highlighted with a yellow marker
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41 1098 on each topoplot.

48 1099 **Fig. 6.** Event-related potentials associated with executive vigilance as a function of overall
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50 1100 performance (a and b) and the decrease in hits (c and). Signal amplitude target-locked as a
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52 1101 function of hits and misses at (a) Pz for P1, N1, and P3 components and (b) Cz and adjacent
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54 1102 channels for SP component. Signal amplitude target-locked for hits as a function of task period
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56 1103 (first/last) at (c) Pz for P1, N1, and P3 components and (d) Cz and adjacent channels for SP
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58 1104 component. In all amplitude signal plots, significant differences ($p < .05$) between conditions
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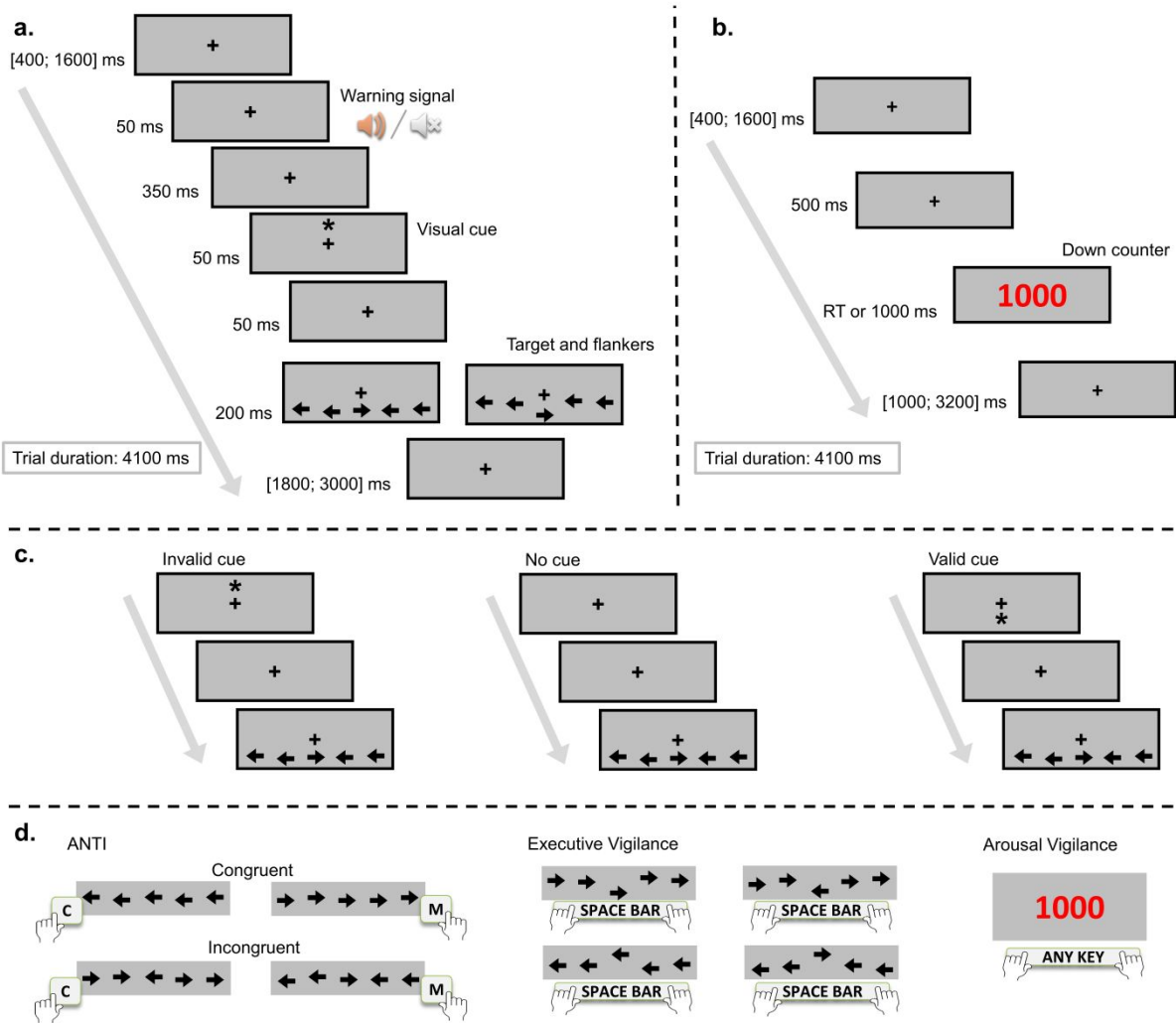
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3 1105 at each time point are highlighted with a black line above the x-axis. Shadowed traces around
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5 1106 mean signal represent within-participant 95% CI of mean for that condition and were computed
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7 1107 with the Cousineau-Morey method (Morey, 2008). Topoplots represent misses minus hits
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9 1108 signal in (a) and (b), and last minus first period signal for hits in (c) and (d). Channels of interest
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11 1109 (named in each figure title) are highlighted with a yellow marker on each topoplot.
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15 1110 **Fig. 7.** Event-related potentials associated with arousal vigilance performance. Signal
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17 1111 amplitude target-locked as a function of reaction time (fastest/slowest) at (a) O1, (b) Oz, and
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19 1112 (c) O2, for N1 and P2 components. In all amplitude signal plots (a, b, and c), significant
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21 1113 differences ($p < .05$) between conditions at each time point are highlighted with a black line
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23 1114 above the x-axis. Shadowed traces around mean signal represent within-participant 95% CI of
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25 1115 mean for that condition and were computed with the Cousineau-Morey method (Morey, 2008).
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27 1116 (d) Topoplots represent slowest minus fastest reaction time' signal for N1 (260 ms) and P2
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29 1117 (390 ms). In all topoplots, channels of interest are represented with a yellow marker for that
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33 1118 component.
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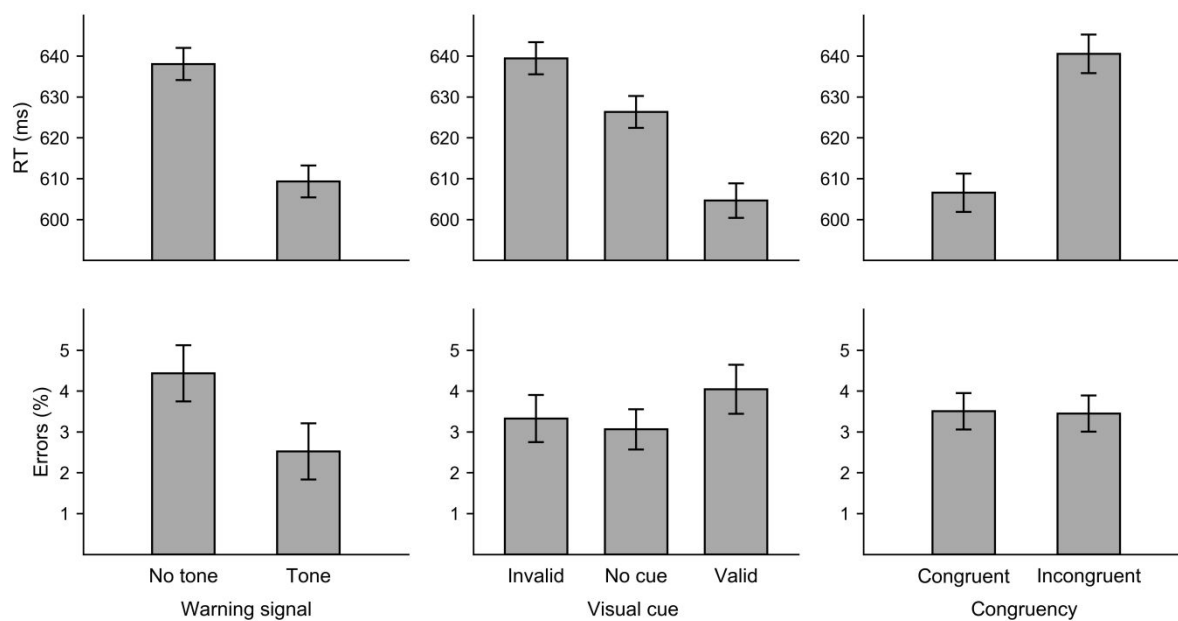
Figures

1120 **Figure 1.**



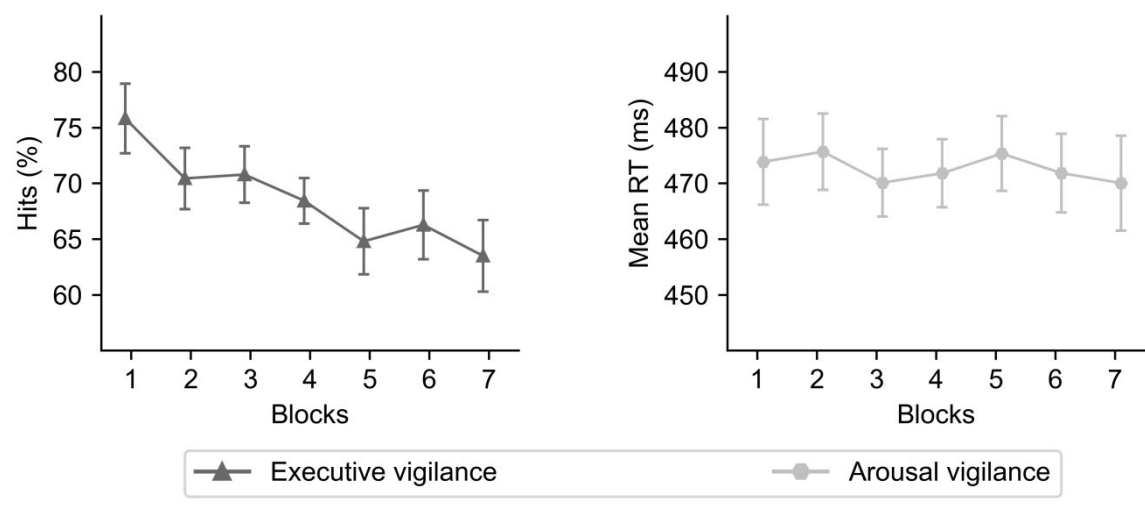
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1122 **Figure 2.**



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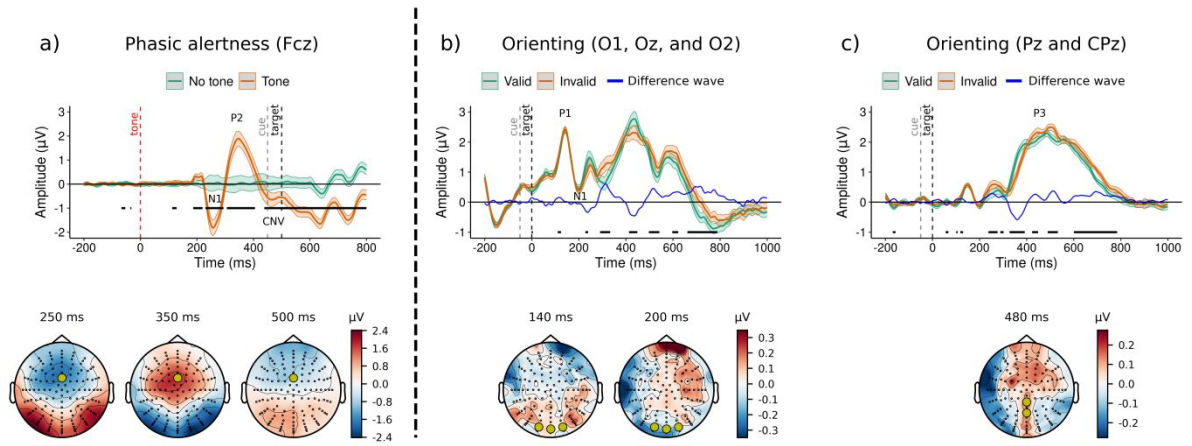
1124 **Figure 3.**



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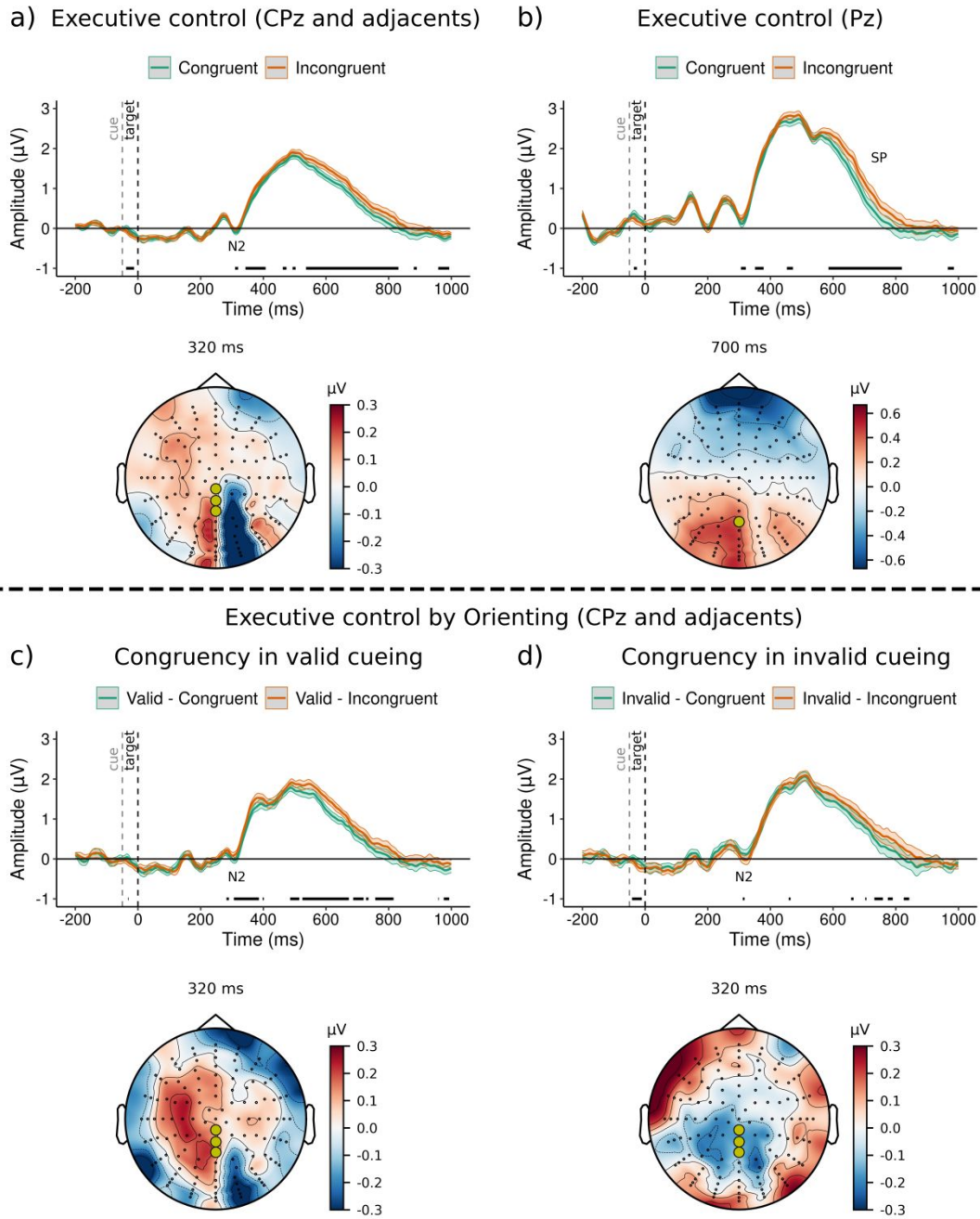
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1126 **Figure 4.**



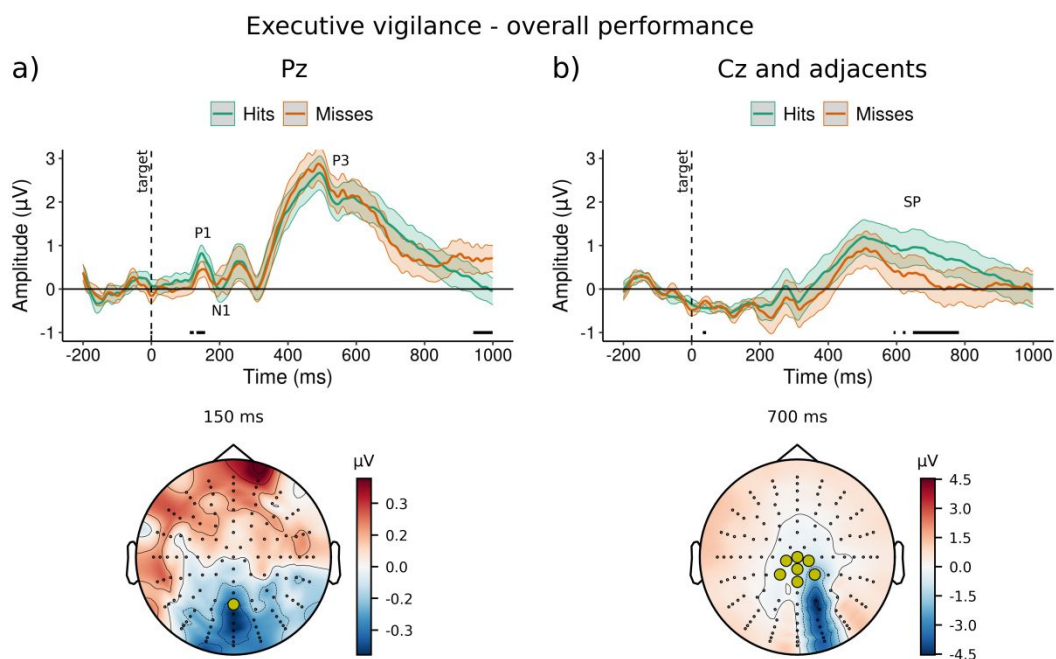
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1128 **Figure 5.**

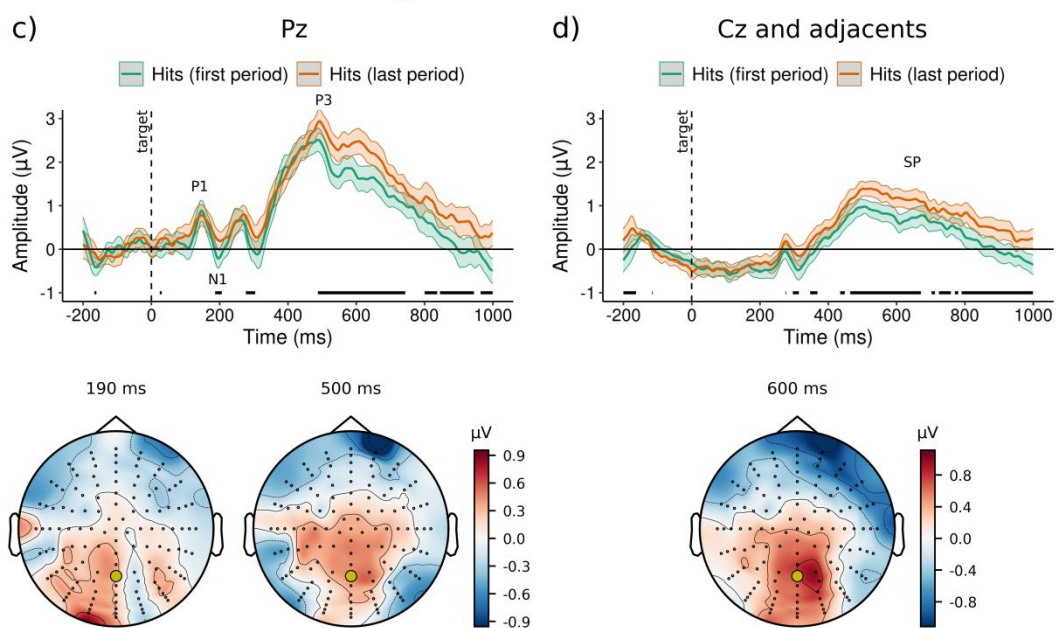


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1130 **Figure 6.**

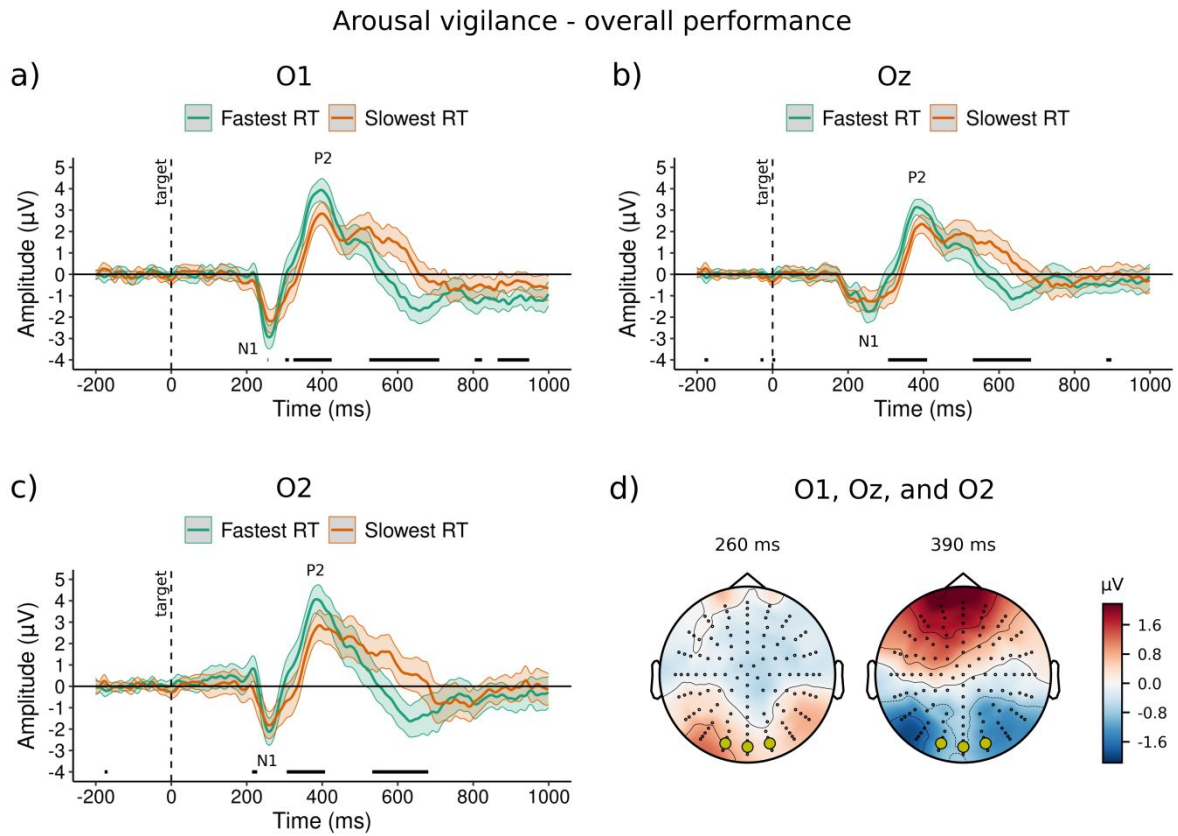


Executive vigilance across time-on-task



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1132 **Figure 7.**



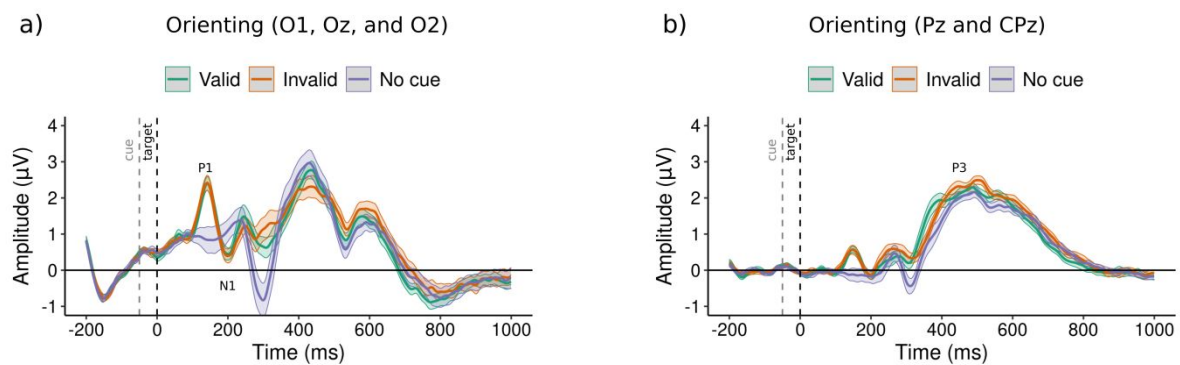
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Supplementary Material

Supplementary Figure 1. Event-related potentials associated with the orienting network.

Signal amplitude locked at target stimuli (dashed vertical black line) as a function of valid/invalid/no cue conditions at the average of (a) O1, Oz, and O2 and (b) CPz and Pz channels. Shaded traces around mean signal represent within-participant 95% CI of mean for that condition and were computed with the Cousineau-Morey method (Morey, 2008).

Note that signal between valid/invalid and no cue conditions is similar at baseline.



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3 **Supplementary Figure 2.** Event-related potentials associated with the modulation of
4 executive control by the orienting network. Signal amplitude locked at target stimuli (dashed
5 vertical black line) as a function of valid/invalid/no cue conditions at the average of CPz and
6 adjacent channels for (a) congruent and (b) incongruent trials. Shaded traces around mean
7 signal represent within-participant 95% CI of mean for that condition and were computed
8 with the Cousineau-Morey method (Morey, 2008). Note that signal between valid/invalid and
9 no cue conditions is similar at baseline and that N2 is observed in the same time window in
10 valid/invalid and no cue conditions.
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