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## The ANTI-Vea task: analyzing the executive and arousal vigilance decrements while measuring the three attentional networks

Fernando G. Luna<sup>\*1,2</sup>, Pablo Barttfeld<sup>1</sup>, Elisa Martín-Arévalo<sup>2</sup> and Juan Lupiáñez<sup>\*2</sup>

<sup>1</sup>*Instituto de Investigaciones Psicológicas (IIPsi, CONICET-UNC), Facultad de Psicología, Universidad Nacional de Córdoba, Córdoba, Argentina*

<sup>2</sup>*Department of Experimental Psychology, and Mind, Brain and Behavior Research Center (CIMCYC), University of Granada, Granada, Spain*

The vigilance decrement phenomenon has been traditionally studied by simple and monotonous behavioral tasks. Nowadays, however, there is considerable interest in measuring vigilance with more complex tasks, including independent measures of other attentional functions. In the present study, we provide evidence supporting the suitability of the Attentional Networks Test for Interactions and Vigilance – executive and arousal components (ANTI-Vea) as an appropriate method to simultaneously assess multiple attentional and vigilance components. Vigilance was examined as two dissociated components: executive vigilance –as the detection of infrequent signals– and arousal vigilance –as the sustenance of a fast reaction to stimuli without response selection–. Importantly, the executive vigilance decrement was analyzed with a novel methodological approach to particularly determine whether the sensitivity loss effect is influenced by a floor level on the false alarms. As expected, the ANTI-Vea proved to be a task suitable to assess: (a) the main effects and interactions of phasic alertness, orienting, and executive control; (b) the executive vigilance decrement as a progressive

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**\*Corresponding author:** Correspondence concerning this article should be addressed either to Fernando G. Luna, Instituto de Investigaciones Psicológicas (IIPsi, CONICET-UNC), Facultad de Psicología, Universidad Nacional de Córdoba, Boulevard de la Reforma esquina Enfermera Gordillo, CP 5000, Córdoba, Argentina, e-mail: fluna@unc.edu.ar, telephone: (54) (0351) 5353890 internal: 60201; or Juan Lupiáñez, Department of Experimental Psychology, and Mind, Brain, and Behavior Research Center (CIMCYC), University of Granada, Campus de Cartuja S/N, CP 18011, Granada, Spain, e-mail: jlupiane@ugr.es, telephone: (34) (958) 243763.

change in the response bias; and (c) the arousal vigilance decrement as a progressive slowness and variability in reaction time. We discuss some critical theoretical and empirical implications of measuring vigilance components with the ANTI-Vea task. We expect the present study to provide a suitable method to analyze the vigilance decrement phenomenon when measuring multiple attentional and vigilance functions.

One of the central mechanisms supported by the attentional networks system –i.e., alerting, orienting, and executive control (Petersen & Posner, 2012; Posner & Petersen, 1990)– is the challenging ability to sustain attention over extended periods; a mechanism scientifically known as ‘vigilance’ (Adams, 1987; Hancock, 2017; Scerbo, 1998; Warm, Parasuraman, & Matthews, 2008). Traditionally, vigilance has been studied by simple and monotonous behavioral tasks such as the Mackworth Clock Test (MCT; Mackworth, 1948) or the Psychomotor Vigilance Test (PVT; Lim & Dinges, 2008), in which a progressive decrement on performance is commonly observed as a function of time on task (Langner & Eickhoff, 2013; Mackworth, 1948; Scerbo, 1998). Currently, nevertheless, there is raising interest in assessing vigilance with more complex tasks, including measures from other attentional components in contrast with the classic approach of measuring vigilance with such simple and monotonous behavioral tasks (Roca, García-Fernández, Castro, & Lupiáñez, 2018; Tkachenko & Dinges, 2018; Wickens, Hutchins, Laux, & Sebok, 2015).

Furthermore, it is important to note that behavioral tasks such as the MCT and the PVT indeed seem to assess two dissociated components of vigilance (Luna, Marino, Roca, & Lupiáñez, 2018). On the one hand, in the PVT (Lim & Dinges, 2008) vigilance is exclusively measured as the capacity to sustain a fast reaction to any stimuli from the environment, without implementing any control on the selection of the executed response. In particular, participants must stay alert over 10 minutes to stop, as fast as possible, and by pressing any available key, a millisecond counter that appears at random intervals from 2 to 10 seconds (Basner & Dinges, 2011). Importantly, participants do not have to be continuously selecting among different response’s options and stimuli, as the same simple response is to be given to the only possible stimulus. Thus, the PVT seems to assess an arousal component of vigilance, a mechanism that could be more related to the physiological shifts in the excitability levels that oscillates during the sleep-wake cycle (Drummond et al., 2005; Lim & Dinges, 2008; Tkachenko & Dinges, 2018). Indeed, note that the PVT is very sensitive to the effects of total or partial sleep deprivation (Basner & Dinges, 2011; Drummond et al., 2005). In the PVT, the arousal vigilance (AV) decrement is observed as a

progressive increment across time on task in reaction time (RT) scores, as mean, variability, and lapses (i.e., excessively slow RT; Lamond et al., 2008; Lamond, Dawson, & Roach, 2005; Loh, Lamond, Dorrian, Roach, & Dawson, 2004).

On the other hand, in signal detection tasks such as the MCT (Mackworth, 1948) or the Sustained Attention to Response Task (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997), vigilance is examined as the ability to monitor and detect critical signals that occur quite rarely over an extended period. For instance, in the MCT, participants must remain alert to detect the occurrence of an unusual double jump of the clock hand (Mackworth, 1948). This type of task seems to assess an executive component of vigilance, which implements controlled mechanisms of sustained attention to categorize stimuli from the environment and selectively detect the appearance of critical signals, while avoiding responding to the remaining noise stimuli. Importantly, at difference with the PVT, in signal detection tasks the executive vigilance (EV) decrement is observed as a progressive loss on hits to correctly detect the infrequent signals (See, Howe, Warm, & Dember, 1995; Thomson, Besner, & Smilek, 2016).

Note that, traditionally, by using Signal Detection Theory (SDT) metrics it has been assumed that the decrement on hits corresponds to a progressive loss in the sensitivity to discriminate the occurrence of critical signals from the remaining noise events, e.g., the regular jump of the clock hand on the MCT (See et al., 1995). However, a recent review and empirical demonstration by Thomson et al. (2016) has pointed out several flaws in simple signal detection tasks to properly determine the potential shifts of SDT metrics across time on task. To start with, simple and monotonous tasks are generally very easy to perform. Consequently, in the first period of the task, a ceiling effect on the hits rate is commonly observed along with a floor effect on the false alarms (FA) rate. This is a critical issue because if FA are at floor levels at the beginning of the task, there is no possibility for the decrement on hits to be accompanied by a similar decrement on FA, which would mask the likely shift in the response bias across time on task.

To test this hypothesis, Thomson et al. (2016) developed a novel vigilance paradigm in which the noise events included a low proportion of lure trials. Critically, the lure trials should be specifically more difficult to discriminate from the signal events than the remaining non-lure trials. Participants had to perform a categorical decision task over serially presented words, trying to respond only to those words representing four-legged creatures (e.g., 'squirrel', 10 per block). In the remaining noise events, most of them represented inanimate objects (e.g., 'phone', 80 per block as non-lure trials). Furthermore, and importantly, a low proportion of lure trials were

words representing non four-legged creatures (e.g., ‘canary’, 10 per block). As predicted by Thomson et al., in the first period of the task the FA rate increased importantly (i.e., ~33%) when it was computed considering only the lure trials, in contrast to the FA rate when considering all trials (i.e., ~5%). Importantly, FA computed from the lure trials showed a prominent decrement across time on task, and consequently, the vigilance decrement was observed as an increment in the response bias and not as a loss in sensitivity (Thomson et al., 2016). Note that the results observed by Thomson et al. were later replicated using the same vigilance task in a recent study conducted by Claypoole, Neigel, Fraulini, Hancock, & Szalma (2018).

To obtain a direct measure of both vigilance components along with an independent measure of other functions of the attentional networks system, we have recently developed the Attentional Networks Test for Interactions and Vigilance – executive and arousal components (ANTI-Vea; Luna et al., 2018). In short, the task combines three different attentional and vigilance tasks randomly embedded within a single session. In the largest proportion of trials (i.e., 60%), participants have to complete the Attentional Networks Test for Interactions (ANTI) developed by Callejas, Lupiáñez, and Tudela (2004); a flanker paradigm with visual cues and warning signals that is useful to assess the classic attentional networks functions, i.e., phasic alertness, orienting, and executive control (Petersen & Posner, 2012; Posner & Petersen, 1990). The EV task consists in detecting an infrequent vertical displacement of the target (i.e., the central arrow of a five-arrow string is vertically displaced in 20% of the trials). In the remaining 20% of trials, participants perform an AV task, in which a millisecond counter has to be stopped as fast as possible by pressing any key from the keyboard.

Importantly, the ANTI-Vea has proven to be a task suitable to assess multiple attentional and vigilance components at the same time (Luna et al., 2018). In particular, the usual main effects and interactions of the classic attentional functions were observed as with the ANTI task (Callejas, Lupiáñez, Funes, & Tudela, 2005; Callejas et al., 2004). Furthermore, and importantly, clear decrements were observed for both EV and AV. In particular, the EV decrement was found as a progressive increment in the response bias, rather than as a loss in sensitivity, in the same vein that the empirical demonstration by Thomson et al. (2016). Moreover, the AV decrement was observed as a linear increment in the mean and variability of RT, as usually observed with the PVT (Basner & Dinges, 2011). It is important to highlight that the ANTI-Vea has shown to be useful to dissociate the two components of vigilance, as they seem to be differently modulated by caffeine intake and exercise intensity (Sanchis, Blasco, Luna, & Lupiáñez,

2020) and by transcranial direct current stimulation (Luna, Román-Caballero, Barttfeld, Lupiáñez, & Martín-Arévalo, 2020).

## **THE PRESENT STUDY**

The main goal of the present study was to investigate the appropriate parameters of the ANTI-Vea for it to be a suitable task to assess both the EV and AV decrement along with the independence and interactions of the classic attentional networks functions, while avoiding a floor effect on FA so that the EV decrement can be appropriately interpreted. To achieve this goal, we applied the methodological approach developed by Thomson et al. (2016) to two different versions of the ANTI-Vea: the ‘standard’ and the ‘lure’ version of the ANTI-Vea. Based on the standard version of the ANTI-Vea, we designed a lure version, which included a low proportion of trials wherein we expected to importantly increase the FA rate. Then, we adapted the analytical method of Thomson et al. to compute a corrected FA rate in both the standard and the lure ANTI-Vea, considering only those trials wherein it was more likely to commit a FA. Therefore, once avoided a possible floor level on the FA rate, we examined whether FA either increase or decrease across time on task to critically test whether the EV decrement is actually due to a decrease in sensitivity or to an increase in the response criterion (or perhaps due to changes in both sensitivity and response criterion). Following Thomson et al., we hypothesized that if FA decrease across time on task –or at least do not increase–, the EV decrement will be more likely observed as a change in the response bias rather than as a loss in sensitivity.

Importantly, note that we expected to observe independent behavioral patterns for the vigilance and attentional functions measured with the ANTI-Vea task (Luna et al., 2018). Therefore, while the EV decrement was anticipated as a drop in the correct detection of critical signals, we anticipated the AV decrement as a progressive slowness and variability in RT, in the same vein as usually reported with the PVT (Basner & Dinges, 2011; Lim & Dinges, 2008). Regarding the classic attentional networks functions, we expected to observe the typical effects reported with the ANTI (Callejas et al., 2004). In particular, for the phasic alertness functioning, we expected faster responses when the stimuli are anticipated by a warning signal than when they are not anticipated. Regarding attentional orienting, we expected valid visual cues to speed up target selection, and invalid cued to slow it down, compared to when no visual orienting cue is presented. Lastly, for the executive control network, we anticipated that the presence of incongruent distractors would impair target selection as compared to congruent

distractors. The materials and data set of this study are publicly available in the Open Science Framework, at <https://osf.io/awz3g/>.

## METHOD

**Participants.** In a recent study conducted with the ANTI-Vea task (Luna et al., 2018), we observed that a sample size of 80 participants ( $n = 40$  per group) was appropriate to observe a reliable main effect of the change in the response bias (the smallest vigilance decrement of interest) across the six experimental blocks ( $\eta_p^2 = .04$ , for which a minimum of 35 participants per group would be necessary, with an  $\alpha = .05$  and a power of  $1 - \beta = .90$ ). Therefore, we decided to gather data from a similar sample size in the present experiment. A total of 86 healthy volunteers (61 women; age  $M = 22.70$ ,  $SD = 5.54$ ; education years:  $M = 13.95$ ;  $SD = 1.30$ ), all of them with normal or corrected to normal vision, participated in this study. All participants were undergraduate students from the Universidad Nacional de Córdoba, Argentina. They signed a written informed consent and completed the session individually. The study was conducted according to the ethical standards of the 1964 Declaration of Helsinki (last update Seoul, 2008) and was part of a larger research project approved by the Universidad de Granada Ethical Committee (175/CEIH/2017). Participants were randomly assigned to one of two groups, depending on the task version performed. Groups did not differ in age [ $t(84) = -0.32$ ,  $p = .75$ ] or education years [ $t(84) = 1.16$ ,  $p = .25$ ].

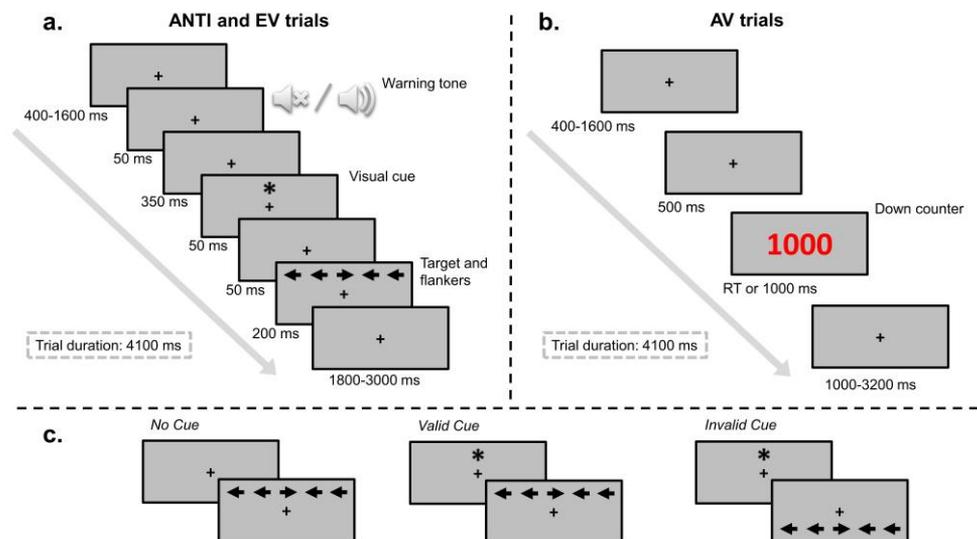
**Stimuli and design.** The experimental tasks were designed and run in E-Prime v2.0 Professional (Psychology Software Tools, Pittsburgh, PA). All stimuli and instructions were drawn in black against a grey background. Responses were registered by pressing one key on a standard QWERTY keyboard.

Participants sat at ~50 cm from the screen, which had a resolution in pixels (px) of 1024 wide and 768 height. Stimuli and timing were the same as in the original ANTI-Vea (Luna et al., 2018): a black fixation cross (~7 px), a black asterisk (~13 px), a warning tone (2000 Hz, presented through headphones), a red millisecond down counter (~110 px height each number), and a row of five black arrows (50 px wide x 23 px high each arrow) pointing either leftward or rightward. The horizontal distance between adjacent arrows was set at ~63 px.

**Procedure and design.** *Self-report questionnaires and assessment of fatigue.* Before the experimental task, participants completed the following questionnaires: (a) Insomnia Severity Index (Bastien, Vallières, & Morin, 2001), (b) Cognitive Failures Questionnaire (Broadbent, Cooper, FitzGerald, & Parkes, 1982), (c) Attentional Control Scale (Derryberry & Reed, 2002),

and (d) Barratt Impulsiveness Scale-11 (Patton, Stanford, & Barratt, 1995). In addition, participants self-reported their level of mental and physical fatigue at three different times across the session: before instructions and practice blocks, before starting the experimental task, and at the end of the experimental blocks. The goal of collecting these data is to assess the relationship between several self-reported abilities, habits, and sensations, with the performance' scores of the attentional and vigilance components measured with the ANTI-Vea task. Note, however, that this goal is part of a larger project, so that data of the present study will be reported elsewhere when data from a much larger  $N$  is accumulated.

*Attentional Networks Test for Interactions and Vigilance – executive and arousal components (ANTI-Vea)*. The ANTI-Vea task comprises three different types of trials: ANTI (60%, to assess the classic attentional networks functions and their interactions), EV (20%, a signal detection task similar to the MCT), and AV (20%, a vigilance task similar to the PVT). The stimuli sequence and procedure for all trials can be observed in Fig. 1.



**Figure 1.** ANTI-Vea design. Experimental procedure and stimuli sequence of (a) both ANTI and Executive Vigilance (EV) trials and (b) Arousal Vigilance (AV) trials. Responses were allowed until 2000 ms since the target or the down counter presentation. (c) Examples of visual cue conditions.

In the ANTI trials, a row of five arrows was presented either above or below the fixation point. Participants had to respond to the direction of the target (i.e., the central arrow) while ignoring the direction pointed by the flanking arrows. To measure executive control, half of the times the target direction was congruent with the flankers' direction, whereas in the other half

it was incongruent (see examples of congruency conditions in Fig. 2). Previously, to assess phasic alertness functioning, in 50% of these trials a warning signal was presented 500 ms before the appearance of the arrows (tone condition), whereas no warning signal was presented in the remaining 50% of the trials (no tone condition). Finally, for measuring the orienting functioning, a spatially non-predictive visual cue was presented 100 ms before the arrows in 2/3 of the trials, whereas no visual cue was presented in the remaining 1/3 of the trials. When presented, the cue could be at the same location as the target (valid location condition), or at the opposite condition (invalid location condition). Examples of warning signal and visual cue conditions can be observed in Fig. 1.

EV trials had the same procedure as ANTI trials (see Fig.1), except that the target was displaced from the central position (see Fig. 2). In the EV trials, participants were encouraged to remain vigilant to detect as the critical signal a large vertical displacement (i.e., 8 px) of the target from its central position by pressing the space bar, ignoring in these cases the direction pointed by the target. Lastly, in the AV trials (see Fig. 1), a down counter was presented instead, and participants were instructed to stop it as fast as possible by pressing any key from the keyboard.

Note that the EV task of the ANTI-Vea presents a 2-alternative-forced-choice task, in which participants have to discriminate the critical signal (i.e., the 8 px vertical displacement of the target from its central position in the EV trials) from the remaining noise events (i.e., all the ANTI trials, wherein the target is not displaced 8 px from its central position; see Fig. 2). Thus, following the two possible responses admitted in a 2-alternative-forced-choice task: (a) hits are the correct responses to the EV trials (i.e., pressing the 'space bar' to the 8 px displacement of the target); (b) misses (i.e., the complement of hits) are the incorrect responses to the EV trials, i.e., not pressing the space bar to the 8 px displacement of the target; (c) FA are the incorrect detections of the infrequent signal in the noise events (i.e., the 'space bar' responses in any of the ANTI trials); and (d) correct rejections (i.e., the complement of FA) are not responding with the space bar to the trials with a displacement smaller than 8 px, in other words, responding instead with the responses expected to the noise events (i.e., either the 'c' or 'm' responses in any ANTI trials).

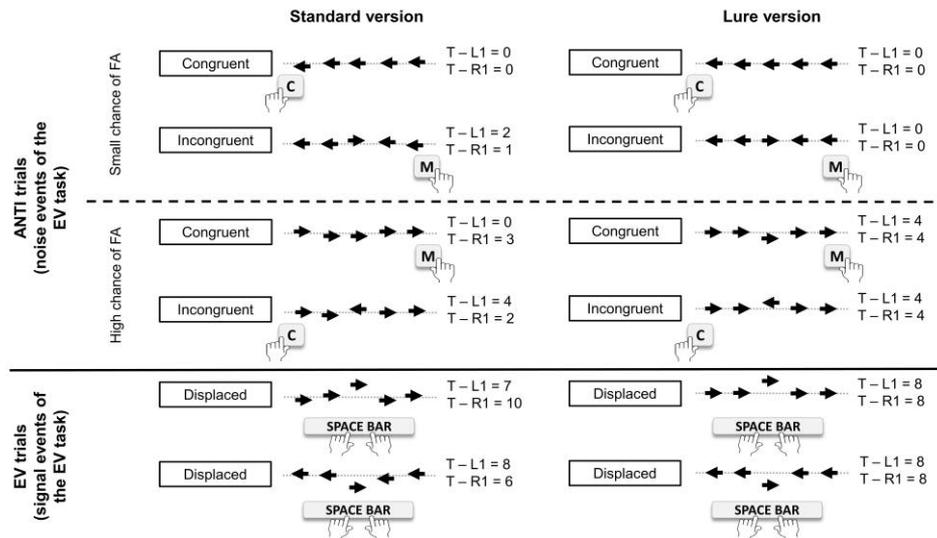
Each group of participants completed a different version of the ANTI-Vea task: the standard –as in Luna et al. (2018)–, or the lure task version. Importantly, the only difference between the standard and the lure version was the possible positions for target and flankers stimuli on each trial. In the standard task, a random variability of  $\pm 2$  px was set for the horizontal and vertical position of the arrows, both in the ANTI (for target and flankers) and

EV (only for flankers) trials. This variability on the arrows' position was introduced to make more difficult the detection of the larger and fixed 8 px displacement of the target (either up or down) in the EV trials (see examples in Fig. 2).

On the other hand, in the lure version, the arrows' position was set differently (see Fig. 2) to design a vigilance task similar to the one proposed by Thomson et al. (2016). The  $\pm 2$  px noise was eliminated so that the flanking arrows appeared in a fixed position, for both ANTI and EV trials. However, in the ANTI trials of the lure version, there was 1/3 of trials wherein the target had a fixed displacement (4 px, either up or down) smaller nevertheless than the one of the EV trials (i.e., 8 px), while in the remaining 2/3 of ANTI trials the target appeared fixed in the center of the row of arrows without any displacement. Importantly, with these manipulations over the position of the stimuli, we expected that participants would commit more FA (i.e., to erroneously press the space bar) in those ANTI trials wherein the target was displaced 4 px from its central position, as the 4 px displacement could be incorrectly confused with the 8 px displacement of the target in the EV trials.

Given the possible positions of the target and the flankers in the standard and the lure versions, in both task versions, there were some ANTI trials (i.e., the non-signal or noise events of the signal detection task) in which we expected to observe a higher FA rate, indicated in Fig. 2 as ANTI trials with a high chance of FA. In the lure task version, these were ANTI trials wherein the target was displaced 4 px from its central position, just explained.

In the standard version, however, those trials were not pre-specified. Therefore, we categorized offline the ANTI trials as a function of the maximum distance (in the vertical axis) between the target and the closest adjacent flankers. This distance (see Fig. 2) could be in a range from 0 px (e.g., the target and both adjacent flankers appeared in the same vertical position) to 4 px (e.g., the target was 2 px displaced in one direction and one of the closest adjacent flankers was displaced 2 px in the opposite direction). Then, in those trials wherein this maximum distance was between 0 and 2 px, we assumed that it was less likely that the target displacement could be confused with the one of the EV trials (i.e., the 8 px displacement) and therefore there was a small chance to commit FA (as the non-displacement trials in the lure version). Instead, in those trials wherein this distance was 3 or 4 px, it could be more probable to commit a FA, as in the trials with the 4 px displacement of the lure task (see Fig. 2). This categorization of the ANTI trials (i.e., the set of trials from which it was computed the FA rate) was necessary for our goal of analyzing whether a floor effect on the FA rate could be affecting the sensitivity and response bias indices.



**Figure 2.** Target and distractors positions in the standard and lure ANTI-Vea versions, EV trials, and for ANTI trials with a high and small chance of committing a FA. The dotted gray line was not presented in the screen and it represents the central height for arrows in the vertical axis for both above or below the fixation point. Subtractions on the right of each example show the distance in pixels between the target (T) and the immediate left (L1) or right (R1) distractor. The correct answer for each example is shown below the arrows.

Before the experimental task, participants received specific instructions for each type of trial and performed several practice blocks with visual feedback. Further details on the sequence of instructions and practice are described in Luna et al. (2018). The experimental section of the task included six blocks of 80 randomly presented trials (48 ANTI, 16 EV, and 16 AV) without any pause or feedback. Given that each trial had a total time duration of 4100 ms (see Fig. 1), the average time for each experimental block was 5:28 min and for the whole task (i.e., the total vigilance period) of ~33 min.

The 48 ANTI trials had the following factorial design: 2 (warning signal: no tone/tone)  $\times$  3 (visual cue: invalid/no cue/valid)  $\times$  2 (congruency: congruent/incongruent)  $\times$  2 (target direction: left/right)  $\times$  2 (arrows position with respect to the fixation point: above/below). The two last factors were introduced for stimuli presentation but not considered in posterior analyses. In the lure version, the 16 ANTI trials wherein the target was displaced 4 px from its central position were randomly selected per block. Lastly, in the EV trials, one factor was added to the design: displacement direction (up/down). The 16 EV trials per block were randomly selected from the 96 possible combinations.

**Data analyses.** Analyses were performed in Statistica 8.0 (StatSoft Inc.) and figures were made with Matplotlib 3.0.0 (Hunter, 2007). First,

following the criteria from Luna et al. (2018), seven participants were excluded from further analyses either due to an extreme average RT in the ANTI trials (2.5 *SD* above the group average) or to a performance unusually low in the ANTI task (i.e., equal or higher than 25% of errors). Thus, in the following analyses, 40 participants were included in the standard version group and 39 in the lure one. Data analyses were conducted separately for the ANTI, EV, and AV tasks. The significance level was established at .05. In addition, statistics are reported with partial eta squared ( $\eta_p^2$ ) as a measure of the effect size and 95% confidence intervals around them (Cumming, 2014; Kelley & Preacher, 2012).

In the ANTI trials, RT analyses excluded trials with incorrect responses (7.79%) and those with RT below 200 or above 1500 ms (0.61%). Then, two mixed analysis of variance (ANOVA) were conducted, one for RT and another for the percentage of errors as dependent variables, and including warning signal (no tone/tone), visual cue (invalid/no cue/valid), and congruency (congruent/incongruent) as within-participants factors, and task version (standard/lure) as a between-participants factor.

To analyze the vigilance decrement across time on task, EV and AV measures were obtained per block of trials. For EV trials, warning tone, visual cue, and congruency were not considered for analyses, with data being collapsed across these variables. Hits were computed as the proportion of infrequent signals (i.e., the 8 px displaced targets) correctly detected. Then, following the methodological approach by Thomson et al. (2016), FA (i.e., the ‘space bar’ responses in any of the ANTI trials) were computed in two different ways. The ‘total’ computation of FA included all the noise events (i.e., the whole set of ANTI trials). Instead, the ‘corrected’ computation of FA included only those trials wherein we assumed it was more probable to commit a FA, i.e., the ANTI trials with a 3 to 4 px displacement of the target in the standard task and the ANTI trials with a 4 px displacement in the lure task.

Next, non-parametric indexes of sensitivity ( $A'$ ) and response bias ( $B''$ ) were obtained (J. B. Grier, 1971). Both indices were computed considering either the ‘total’ or the ‘corrected’ FA. The advantages of using non-parametric over classic parametric indices ( $d'$  for sensitivity and  $\beta$  for response bias) can be reviewed in multiple studies (e.g., Stanislaw & Todorov, 1999; Thomson, Besner, & Smilek, 2016). In short, non-parametric indices are distribution free and therefore, at difference with parametric indices, they can be computed when hits and/or FA are equal to 100% or 0% –which are performances frequently observed when scores are computed per experimental block–. Then, seven mixed ANOVAs were conducted separately including task block (6 levels) as a within-participant factor and

task version (standard/lure) as a between-participants factor, one for each dependent variable: hits and the ‘total’ and ‘corrected’ computation of FA, A’ and B”. Importantly, for researchers interested in analyses conducted with parametric indices of sensitivity and response bias, please see the Supplementary Material.

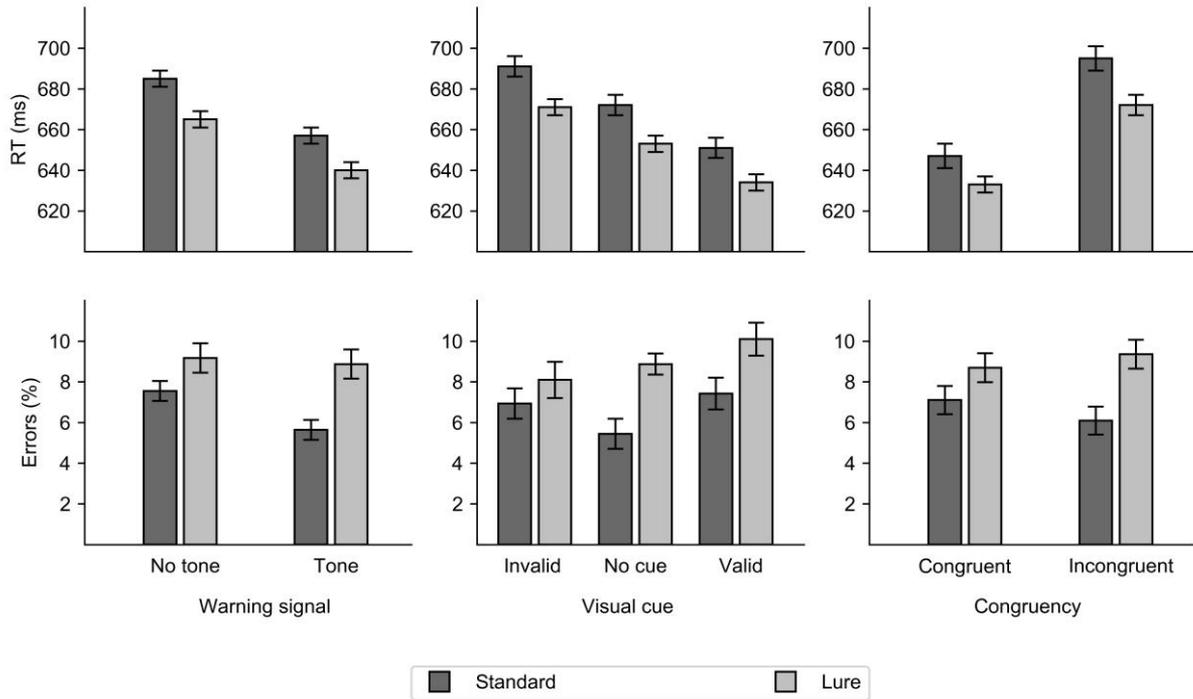
The AV decrement was analyzed considering the mean and *SD* of RT, and the percentage of lapses (i.e., late responses to the down counter) per block. Following Luna et al. (2018), the threshold for lapses was set as responses slower than 600 ms. Then, three mixed ANOVAs were conducted separately, including task block (6 levels) as a within-participant factor and task version (standard/lure) as a between-participants factor, one for each dependent variable: mean RT, *SD* of RT, and percentage of lapses. Importantly, for both the EV and AV components, post-hoc comparisons of the linear component across blocks were performed to determine statistical differences of the vigilance decrement between task versions.

## RESULTS

**Phasic Alertness, Orienting, and Executive Control.** Significant main effects were found for warning signal {RT: [ $F(1, 77) = 85.21, p < .001, \eta_p^2 = .53, 95\% \text{ CIs } (.37, .63)$ ]; errors: [ $F(1, 77) = 6.68, p = .01, \eta_p^2 = .08, (.00, .21)$ ]}, visual cue {RT: [ $F(2, 154) = 94.08, p < .001, \eta_p^2 = .55, (.44, .62)$ ]; errors: [ $F(2, 154) = 6.79, p = .001, \eta_p^2 = .08, (.01, .17)$ ]}, and congruency {only for RT: [ $F(1, 77) = 143.81, p < .001, \eta_p^2 = .65, (.52, .73)$ ]; but not for errors:  $F < 1$ }. Thus, as depicted in Fig. 3, for the warning signal effect responses were faster and more precise in the tone than in the no tone condition. The visual cue effect was observed as usual (invalid > no cue > valid) for the RT, while for errors this effect was marginally modulated by the task version [ $F(2, 154) = 3.16, p = .05, \eta_p^2 = .04, (.00, .11)$ ] (see Fig. 3). In particular, in the standard version the percentage of errors was smaller in the no cue than in the invalid and valid conditions. In the lure version, instead, the percentage of errors was smaller in the invalid than in the no cue and valid conditions. Finally, the congruency effect—which was observed only for RT—showed that responses were faster in the congruent than in the incongruent condition (Fig. 3).

The main effect of task version was not significant for the RT ( $F < 1$ ), with a similar overall RT for the standard ( $M = 671$  ms, 95% CIs [640, 702]) and the lure version ( $M = 653$  ms, [621, 684]). However, this effect was significant for the analysis of errors [ $F(1, 77) = 4.93, p = .03, \eta_p^2 = .06, (.00,$

.18]): in particular, responses were more precise in the standard ( $M = 6.60\%$ , [5.07, 8.12]) than in the lure version ( $M = 9.02\%$ , [7.47, 10.56]).



**Figure 3.** Mean correct RT (superior graphs) and percentage of errors (inferior graphs) for the warning signal (left), visual cue (center), and congruency (right) conditions, as a function of the task version (standard/lure). Error bars represent 95% confidence intervals of the mean and were computed following the method developed by Cousineau (2005).

Regarding the modulations between the attentional networks functions, only the interaction between warning signal and visual cue was significant {only for RT: [ $F(2, 154) = 12.44, p < .001, \eta_p^2 = .14, (.05, .23)$ ]; but not for errors: [ $F(2, 154) = 1.01, p = .37, \eta_p^2 = .01, (.00, .06)$ ]}, whereas the remaining interactions did not reach statistical significance: Warning signal  $\times$  Congruency {RT: [ $F(1, 77) = 3.13, p = .08, \eta_p^2 = .04, (.00, .15)$ ]; errors:  $F < 1$ }, and Visual cue  $\times$  Congruency {RT: [ $F(2, 154) = 2.41, p = .09, \eta_p^2 = .03, (.00, .09)$ ]; errors:  $F < 1$ }. The three way interaction between the three within-participant factors was far from significance for both RT [ $F(2, 154) = 1.15, p = .32, \eta_p^2 = .01, (.00, .06)$ ] and errors [ $F(2, 154) = 1.48, p = .23, \eta_p^2 = .02, (.00, .07)$ ]. Finally, task version did not modulate any other factor or their interactions, neither for RT (all  $F_s < 1.40, p_s > .24$ ) nor for errors (all remaining  $F_s < 2.95, p_s > .09$ ). Table 1 shows the mean RT and errors for each of the ANTI trials conditions.

**Table 1.** Mean correct RT (ms) and percentage of errors of warning signal, visual cue, and congruency conditions as a function of the task version (standard/lure).

		Standard				Lure			
		Congruent		Incongruent		Congruent		Incongruent	
		<i>M</i>	95% CI	<i>M</i>	95% CI	<i>M</i>	95% CI	<i>M</i>	95% CI
Reaction Time									
No tone	Invalid	671	[638, 703]	722	[688, 755]	653	[620, 686]	700	[666, 734]
	No cue	676	[643, 709]	711	[679, 743]	655	[621, 688]	685	[652, 718]
	Valid	643	[607, 680]	685	[652, 718]	632	[595, 669]	666	[632, 699]
Tone	Invalid	656	[624, 689]	713	[680, 746]	642	[609, 675]	688	[655, 721]
	No cue	623	[594, 652]	677	[643, 711]	614	[584, 643]	660	[625, 694]
	Valid	612	[581, 643]	663	[628, 698]	602	[570, 633]	636	[601, 671]
Errors									
No tone	Invalid	8.85	[6.14, 11.57]	7.08	[5.05, 9.12]	8.65	[5.91, 11.40]	8.44	[6.38, 10.50]
	No cue	6.15	[3.94, 8.35]	6.56	[4.38, 8.75]	9.94	[7.70, 12.17]	8.76	[6.55, 10.97]
	Valid	8.23	[5.79, 10.67]	8.44	[5.93, 10.94]	8.76	[6.29, 11.23]	10.47	[7.93, 13.01]
Tone	Invalid	7.19	[4.92, 9.45]	4.58	[2.53, 6.64]	7.16	[4.86, 9.45]	8.12	[6.04, 10.20]
	No cue	5.10	[3.12, 7.09]	3.96	[1.55, 6.36]	6.94	[4.94, 8.95]	9.83	[7.39, 12.27]
	Valid	7.08	[4.36, 9.81]	5.94	[3.51, 8.36]	10.68	[7.93, 13.44]	10.47	[8.01, 12.93]

Note: *M* = mean; CI = confidence intervals.

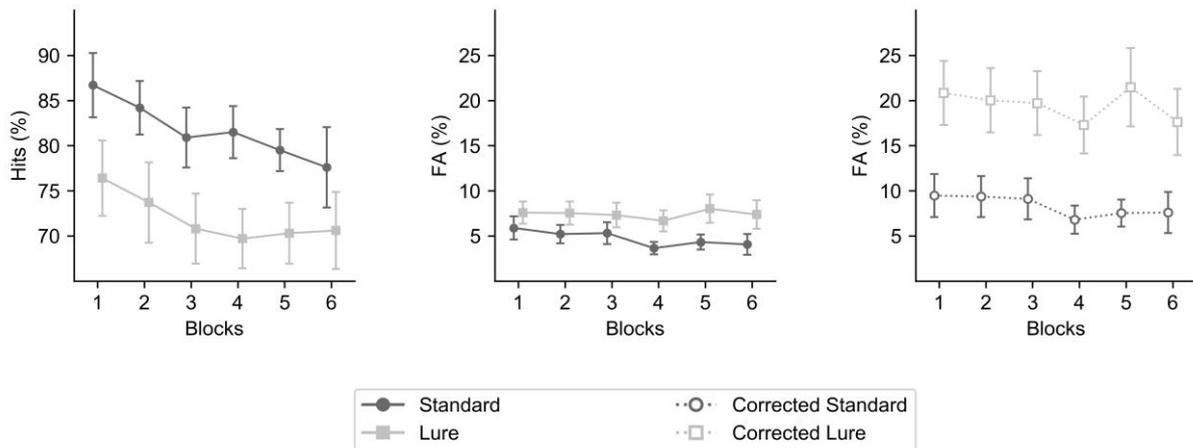
**Executive vigilance decrement.** *Hits.* As depicted in Fig. 4, a significant decrement across blocks was observed on hits [ $F(5, 385) = 4.16, p = .001, \eta_p^2 = .05, (.01, .09)$ ] together with a main effect of task version [ $F(1, 77) = 6.59, p = .01, \eta_p^2 = .08, (.00, .21)$ ]. The overall percentage of hits was higher in the standard ( $M = 81.77\%$ , [76.42, 87.17]) than in the lure version ( $M = 71.96\%$ , [66.54, 77.37]).

The decrease on hits across blocks was not modulated by the task version ( $F < 1$ ). Post-hoc comparisons confirmed that the linear component of blocks observed with each task version did not differ from each other ( $F < 1$ ). However, when task versions were analyzed separately, the linear component was significant in the standard version [ $F(1, 77) = 7.02, p = .009, \eta_p^2 = .08, (.00, .21)$ ], but not in the lure one [ $F(1, 77) = 3.18, p = .08, \eta_p^2 = .04, (.00, .15)$ ].

*False alarms.* FA computed from all trials did not change significantly across blocks [ $F(5, 385) = 1.42, p = .21, \eta_p^2 = .02, (.00, .04)$ ] and it was not modulated by the task version ( $F < 1$ ; see Fig. 4). However, there was a significant main effect for task version [ $F(1, 77) = 8.60, p = .004, \eta_p^2 = .10, (.01, .24)$ ], with a smaller overall percentage of FA in the standard ( $M = 4.74\%$ , [3.46, 6.02]) than in the lure version ( $M = 7.42\%$ , [6.12, 8.71]).

Importantly, as expected and observed in the same Fig. 4, the corrected computation showed an important increase in FA. The main effect of task version [ $F(1, 77) = 22.59, p < .001, \eta_p^2 = .23, (.08, .37)$ ] was larger than in

the computation from all trials, with much more FA in the lure (corrected  $M = 19.50\%$ , [16.16, 22.83]) than in the standard version (corrected  $M = 8.31\%$ , [5.02, 11.60]). Nevertheless, despite the important increase in the corrected FA, no main effect of blocks was observed [ $F(5, 385) = 1.24, p = .29, \eta_p^2 = .02, (.00, .04)$ ] and neither was it modulated by task version ( $F < 1$ ). Post-hoc comparisons confirmed that the linear component of blocks for each task version separately was not significant (both  $F$ s  $< 1.20, p$ s  $> .28$ ).



**Figure 4.** Hits and false alarms (FA) across time on task. The FA rate computed considering all trials is shown in the central graph and the corrected computation of FA is depicted in the right graph. Error bars represent 95% confidence intervals as computed following the method developed by Cousineau (2005).

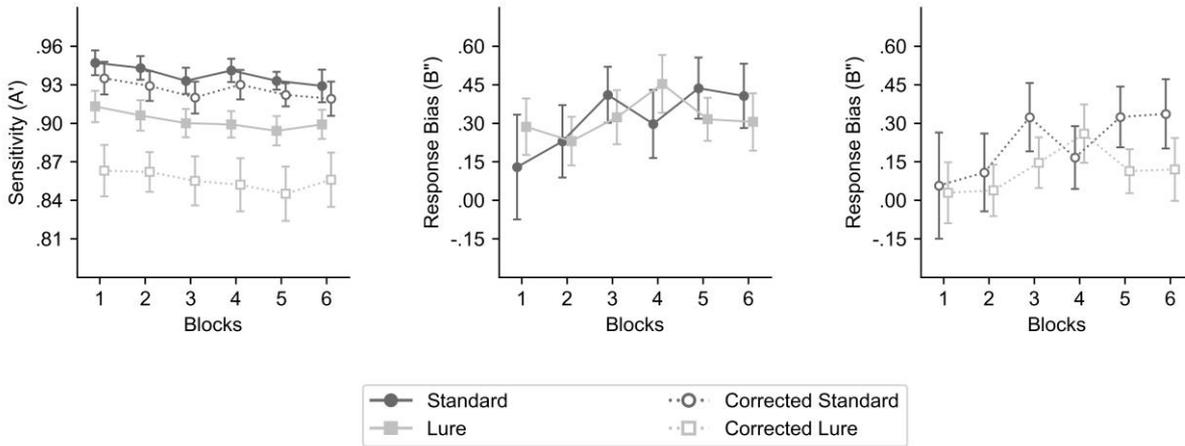
*Sensitivity.* As can be observed in Fig. 5,  $A'$  computed from all trials showed a significant decrement across blocks [ $F(5, 385) = 2.55, p = .03, \eta_p^2 = .03, (.00, .06)$ ], independently of the task version ( $F < 1$ ). In addition, the main effect of task version was significant [ $F(1, 77) = 15.08, p < .001, \eta_p^2 = .16, (.04, .31)$ ], with a higher sensitivity in the standard ( $A' = .94, [.93, .95]$ ) than in the lure version ( $A' = .90, [.89, .92]$ ).

The corrected computation of  $A'$  (i.e., including only the corrected FA) showed an even larger main effect of task version than in the computation from all trials [ $F(1, 77) = 59.37, p < .001, \eta_p^2 = .44, (.27, .56)$ ], with a higher sensitivity in the standard (corrected  $A' = .93, [.91, .94]$ ) than in the lure version (corrected  $A' = .86, [.84, .87]$ ). Most important, as depicted in the same Fig. 5, the corrected computation of  $A'$  demonstrated that sensitivity did not change across blocks ( $F < 1$ ), again independently of task version ( $F < 1$ ). Post-hoc comparisons for corrected  $A'$  confirmed that the linear component of blocks was not significant, neither for the standard [ $F(1, 77)$

= 1.48,  $p = .23$ ,  $\eta_p^2 = .02$ , (.00, .11)] nor for the lure version [ $F(1, 77) = 1.35$ ,  $p = .25$ ,  $\eta_p^2 = .02$ , (.00, .11)].

To test whether the collected evidence regarding  $A'$  computed from corrected trials supports that no change is observed in sensitivity across time on task, we performed a Bayesian analysis. We followed the guidelines suggested by Wagenmakers et al. (2018) to conduct a Bayesian mixed ANOVA with JASP (2019). Compared to the matched model, the Bayesian ANOVA led to a  $BF_{10} = 0.013$  for the effect of blocks, thus providing strong evidence in favor of the null hypothesis (i.e., the absence of change in sensitivity across time on task being  $1/0.013 = 76.92$  times more likely than the change in sensitivity).

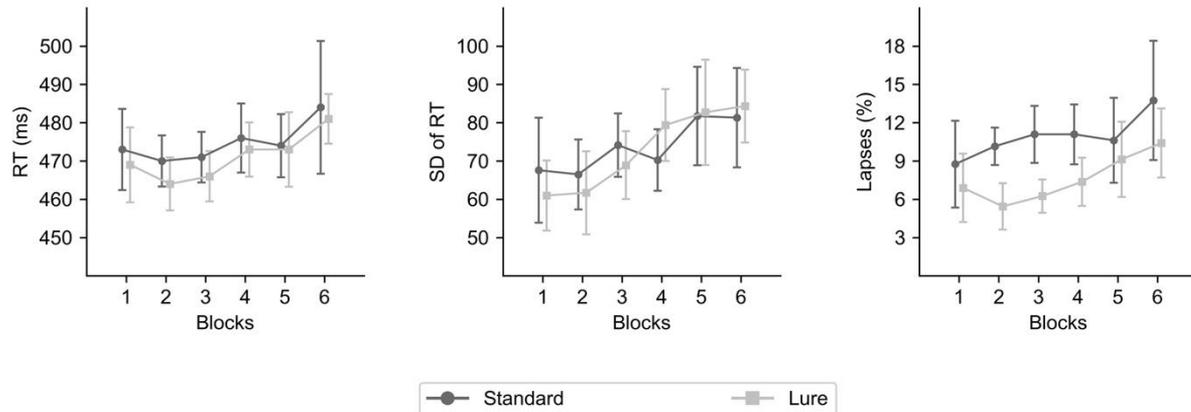
*Response bias.* As can be observed in Fig. 5,  $B''$  computed from all trials showed a significant increment across blocks [ $F(5, 385) = 2.66$ ,  $p = .02$ ,  $\eta_p^2 = .03$ , (.00, .06)]. No main effect of task version ( $F < 1$ ), or Task version  $\times$  Blocks interaction [ $F(5, 385) = 1.79$ ,  $p = .11$ ,  $\eta_p^2 = .02$ , (.00, .05)] were observed. The overall  $B''$  computed from total trials was similar for both the standard ( $B'' = .32$ , [.16, .47]) and the lure version ( $B'' = .32$ , [.16, .48]). Importantly, as depicted in the same Fig. 5, the corrected computation of  $B''$  (i.e., including only the corrected FA) confirmed the increment in response bias across blocks [ $F(5, 385) = 3.03$ ,  $p = .01$ ,  $\eta_p^2 = .04$ , (.00, .07)]. Again, this increment was not modulated by the task version [ $F(5, 385) = 1.52$ ,  $p = .18$ ,  $\eta_p^2 = .02$ , (.00, .04)]. The main effect of task version was not significant ( $F < 1$ ), with a similar overall performance for the standard (corrected  $B'' = .22$ , [.05, .38]) and the lure version (corrected  $B'' = .12$ , [-.05, .29]). Nevertheless, as shown in Fig. 5, when task versions were analyzed separately the linear increment was significant for the standard [ $F(1, 77) = 7.81$ ,  $p = .006$ ,  $\eta_p^2 = .10$ , (.04, .14)], but not for the lure version [ $F(1, 77) = 1.34$ ,  $p = .25$ ,  $\eta_p^2 = .02$ , (.00, .04)], as in the case of hits.



**Figure 5.** Sensitivity and response bias across time on task. The left graph represents the non-corrected and corrected computation of sensitivity. The non-corrected computation of response bias is shown in the central graph and its corrected computation in the right graph. Error bars represent 95% confidence intervals and were computed following the method developed by Cousineau (2005).

**Arousal vigilance decrement. Mean and RT Variability, and lapses percentage.** Fig. 6 shows the significant increment across blocks for mean RT [ $F(5, 385) = 2.51, p = .03, \eta_p^2 = .03, (.00, .06)$ ], SD of RT [ $F(5, 385) = 4.03, p = .001, \eta_p^2 = .05, (.01, .09)$ ], and lapses percentage [ $F(5, 385) = 2.36, p = .03, \eta_p^2 = .03, (.00, .06)$ ]. None of these increments was modulated by the task version (all  $F_s < 1$ ). Considering the two task versions together, post-hoc comparisons confirmed a significant linear increment across blocks for both SD of RT [ $F(1, 77) = 8.95, p = .003, \eta_p^2 = .10, (.05, .15)$ ] and lapses percentage [ $F(1, 77) = 4.60, p = .04, \eta_p^2 = .06, (.01, .10)$ ] and a marginal linear increment for mean RT [ $F(1, 77) = 3.94, p = .05, \eta_p^2 = .05, (.01, .09)$ ].

In general, task versions did not differ significantly for any dependent AV variable (all  $F_s < 1.10, p_s > .29$ ): mean RT (standard = 475 ms, [455, 495]; lure = 471 ms, [451, 491]), SD of RT (standard = 74, [62, 85]; lure = 73, [61, 85]) and lapses (standard = 10.91%, [6.46, 15.36]; lure = 7.59%, [3.08, 12.10]).



**Figure 6.** Arousal vigilance performance across time on task. Mean RT (left graph), SD of RT (central graph), and lapses percentage (right graph). Error bars represent 95% confidence intervals as computed following the method developed by Cousineau (2005).

## DISCUSSION

The present study aimed at providing additional empirical evidence to demonstrate the suitability of the ANTI-Vea task to assess both the EV and AV decrement together with the classic attentional networks functions. To specifically examine the EV component, we extended the methodological approach of Thomson et al. (2016) to the ANTI-Vea aiming at avoiding a floor effect on the FA, so that the EV decrement across time on task can be appropriately interpreted as a progressive loss in sensitivity vs. a change in the response bias towards a more conservative criterion. To this end, we computed a corrected FA rate in two versions of the ANTI-Vea, i.e., the standard task developed in Luna et al. (2018) and a lure version adapted following the experimental design of Thomson et al. Thus, we expected to obtain an appropriate rate of FA (i.e., above the floor level) to avoid the masking of any potential change in the response bias across time on task.

As predicted, we observed a higher FA rate when it was computed only from the corrected trials than from all the noise events, in the same vein as reported by Thomson et al. (2016). Importantly, note that even though in the lure version it was observed a considerable FA rate in the first period of the task (i.e., ~22% considering the corrected computation), neither in the standard nor in the lure version it was found a significant change on FA across blocks. Consequently, the linear drop on hits (which, importantly, started after the first block and was progressive across time-on-task) was not accompanied by an increase or decrease in the corrected computation of FA across time, thus the EV decrement being observed exclusively as a change

in the response bias towards a more conservative criterion. Indeed, and again similar to the outcomes reported by Thomson et al., the sensitivity-loss effect was observed only when it was computed considering FA from all the noise trials, but not when considering the corrected FA.

It is worth noting that, recently, the study of Thomson et al. (2016) received several critics by Fraulini, Hancock, Neigel, Claypoole, & Szalma (2017). These authors questioned the analytical methods carried out by Thomson et al. to obtain SDT metrics. In short, note that in a typical signal detection task based on a 2-alternative-forced-choice paradigm, there are usually two categories of events, i.e., signal and noise (Stanislaw & Todorov, 1999). However, the approach taken by Thomson et al. seems to introduce an additional category of events, i.e., the ‘lure’ ones. Thus, Fraulini et al. objected that in the vigilance task developed by Thomson et al., participants would discriminate events between the three categories and therefore, SDT metrics should be computed considering responses as a function of: (a) signal vs. noise events (i.e., the ‘total’ computation of SDT metrics), (b) signal vs. lure events (i.e., the ‘corrected’ computation), and (c) non-lure vs. lure events, a stimuli discrimination not considered by Thomson et al.

However, it is important to note that this criticism does not apply to our adaptation of Thomson et al. (2016)’ approach to the ANTI-Vea task because there is no real distinction between lure and non-lure events in the ANTI-Vea. This distinction is arbitrary in the ANTI-Vea and only made a posteriori for the purpose of analysis. Therefore, despite the objection stated by Fraulini et al. (2017), the computation of corrected SDT metrics seems to be an adequate approach to analyze the EV decrement in signal detection tasks, at least in tasks like the one embedded in the ANTI-Vea.

Moreover, Fraulini et al. (2017) pointed out that in Thomson et al. (2016) the vigilance task was performed online and outside the lab, without controlling the experimental context. Notwithstanding, Thomson et al. outcomes were replicated later in a study conducted under the typical lab conditions (Claypoole et al., 2018). Indeed, we have recently analyzed the reliability of the vigilance and attentional components of the ANTI-Vea in a study with a large sample ( $N = 617$ ), wherein participants either performed the standard ANTI-Vea in the lab or the online version (<https://www.ugr.es/~neurocog/ANTI/>) outside the lab in a suitable place of their choosing (Luna, Roca, Martín-Arévalo, & Lupiáñez, 2020). In short, we observed that in both task versions, the split-half reliability indices (corrected by the Spearman-Brown prophecy) were higher than .75 for both the EV and AV measures. Most importantly, the EV decrement was only found as a linear increment in the response bias when FA are not at floor in the first block of the task, independently on the task version (lab vs. online).

Furthermore, the present study replicated the fact that the EV decrement can be simultaneously assessed with the AV decrement and the classic attentional functions (Luna et al., 2018), as independently measured by specific tasks like the ANTI (Callejas et al., 2004), the PVT (Lim & Dinges, 2008), and a signal detection task as the MCT (Mackworth, 1948). In particular, we observed the typical main effects and interactions for phasic alertness, orienting, and executive control functions, as usually reported with the ANTI task (Callejas et al., 2005, 2004). Nevertheless, in this version of the ANTI, the classic attentional functions are measured with effects of a similar size (~40 ms each, see Fig. 3). Indeed, the ~40 ms effect of executive control observed with the ANTI-Vea (for a specific analysis of this issue, see Luna, Telga, Vadillo, & Lupiáñez, 2020) is similar to those of phasic alertness and orienting, in contrast with other versions of the task which produce a much larger effect of executive control (between ~60 and ~100 ms; Callejas et al., 2004; Fan, McCandliss, Sommer, Raz, & Posner, 2002; Roca, Castro, López-Ramón, & Lupiáñez, 2011).

The AV decrement was found as usually observed with the PVT: a significant increment across time on task in mean and RT variability, and the percentage of lapses (Basner & Dinges, 2011; Lim & Dinges, 2008). Importantly, whereas no differences were observed between the standard and lure versions regarding AV and the classic attentional functions, it seems that the standard task was more suitable for measuring the EV decrement than the lure one. For instance, in the standard version, we observed a higher percentage of hits, a linear decrement on hits, and a more pronounced increment in the response bias, in comparison with the lure task. Furthermore, the standard version does not suffer from Fraulini et al. (2017)' criticism about the three categories of events, as discussed above. Therefore, although the lure task was tested here as an alternative version of the ANTI-Vea, the standard ANTI-Vea was revealed as the most adequate version of the task.

Future studies might examine whether the ANTI-Vea is a suitable method to overcome some theoretical and empirical limitations observed in the study of the vigilance decrement phenomenon by cognitively simple and repetitive behavioral tasks (Fortenbaugh, DeGutis, & Esterman, 2017; Thomson, Besner, & Smilek, 2015; Thomson et al., 2016). Note that, traditionally, the EV decrement has been examined by simple signal detection tasks wherein it is commonly observed a progressive loss in sensitivity: a behavioral pattern explained by the resources overload model as the consequence of a progressive depletion in the available attentional resources (R. A. Grier et al., 2003; Jun, Remington, Koutstaal, & Jiang, 2019; See et al., 1995; Warm et al., 2008). However, as demonstrated by recent research, the loss in sensitivity might be an artifact of simple vigilance tasks wherein

it is usually observed a floor rate on FA (Claypoole et al., 2018; Thomson et al., 2016).

An alternative account has been proposed by the resources-control model, which predicts that the vigilance decrement might be a consequence of a progressive loss on cognitive control functioning, which is necessary to sustain attentional resources on the task performed at hand. As a consequence, resources are diverted to internal irrelevant thoughts leading to a progressive decrement in vigilance performance (Thomson et al., 2015). Nevertheless, further empirical evidence is necessary to test the predictions stated by the resources-control model, for which a multiple behavioral task as the ANTI-Vea with independent measures of vigilance and cognitive control processes seem to be a more adequate approach than traditional simple signal detection tasks, or tasks measuring executive control but no vigilance decrements, like the one recently used to investigate the decrement in executive control across time on task by Zholdassova, Kustubayeva, & Matthews (2019).

To conclude, the ANTI-Vea has been revealed to be a suitable task to assess simultaneously: (a) the independence and interactions of the classic attentional functions, (b) the EV decrement as a progressive change in the response bias towards a more conservative criterion, and (c) the AV decrement as a progressive slowness and variability in RT, and lapses percentage. Regarding the EV component, we extended the methodological approach developed by Thomson et al. (2016) to the ANTI-Vea to obtain a corrected FA rate, which proved to be useful to avoid a floor level on FA that could mask a potential change in the response bias. Therefore, this approach should be used in the analysis of the EV decrement with the ANTI-Vea task. The present study provides further empirical evidence demonstrating that the EV and AV decrement can be successfully assessed along with multiple attentional functions in a complex task as the ANTI-Vea (Roca et al., 2018; Tkachenko & Dinges, 2018; Wickens et al., 2015). The task has proven to be useful to measure the functioning of the three attentional networks and vigilance (EV and AV) as a function of different variables like age and sport practice (Huertas et al., 2019), or musical practice (Román-Caballero, Martín-Arévalo, & Lupiáñez, 2020). At Open Science Framework (<https://osf.io/awz3g/>) can be found useful tools for the research with the ANTI-Vea task, both with the standard version, as the one used in the present research, and the web-based version ([www.ugr.es/~neurocog/ANTI/](http://www.ugr.es/~neurocog/ANTI/)), that is freely available in different languages.

## **RESUMEN**

Tradicionalmente, el decremento de la vigilancia se ha estudiado con tareas comportamentales simples y repetitivas. Sin embargo, actualmente existe un considerable interés en evaluar la vigilancia con tareas más complejas que incluyan medidas independientes de otros procesos atencionales. En el presente estudio, nuestro objetivo fue proporcionar nueva evidencia empírica sobre la adecuación del Test de Redes Atencionales para Interacciones y Vigilancia – componentes ejecutivo y de activación (ANTI-Vea) para medir simultáneamente múltiples componentes atencionales y de vigilancia. Examinamos la vigilancia como dos componentes disociados: vigilancia ejecutiva –como la detección de señales infrecuentes– y vigilancia de activación –como el mantenimiento de una reacción rápida a los estímulos sin control sobre la respuesta–. Es importante destacar que la vigilancia ejecutiva se analizó con un novedoso método para determinar si un efecto suelo en las falsas alarmas podría influenciar una disminución en la sensibilidad. Como se esperaba, se observó que la tarea ANTI-Vea es adecuada para medir: (a) los efectos principales e interacciones de las funciones de alerta fásica, orientación, y control ejecutivo; (b) el decremento en la vigilancia ejecutiva como un cambio en la tendencia de la respuesta; y (c) el decremento en la vigilancia de activación como un enlentecimiento y variabilidad de la respuesta. Discutimos algunas implicaciones teóricas y empíricas sobre la medición de los componentes de la vigilancia con la tarea ANTI-Vea. Esperamos que el presente estudio provea un método adecuado para analizar el decremento de la vigilancia cuando se evalúan múltiples funciones atencionales y de vigilancia.

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