Commentary

Psychological Science
2023, Vol. 34(1) 132–136

DOI: 10.1177/09567976221121342
www.psychologicalscience.org/PS

Changes in Response Criterion and Lapse Rate as General Mechanisms of Vigilance Decrement: Commentary on McCarley and Yamani (2021)

Rafael Román-Caballero[1], Elisa Martín-Arévalo[1], and Juan Lupiáñez[1]
[1]Department of Experimental Psychology and Mind, Brain, and Behavior Research Center (CIMCYC), University of Granada, Spain

Abstract
Multiple theories have used perceptual sensitivity and response criterion indices to explain the decrements in performance across time on task (i.e., vigilance decrement). In a recent study, McCarley and Yamani (2021) offered conceptual and methodological advances to this debate by using a vigilance task that parametrically manipulates noise and signal and analyzes the outcomes with psychometric curves. In the present Commentary, we reanalyze data ($N = 553$) from a different, already existing vigilance task, the Attentional Networks Test for Interactions and Vigilance—executive and arousal components (ANTI-Vea). Psychometric curves with the ANTI-Vea showed robust changes in response criterion and lapse rate, although not in sensitivity. Our interpretation is that the need to keep the standard in memory in McCarley and Yamani's task could produce a decrease in sensitivity and be related to reduced fidelity of the memory representation rather than to a decrement in perceptual abilities across time on task.

Keywords
vigilance decrement, psychometric curves, memory fidelity, signal detection, open data, open materials

Received 3/16/22; Revision accepted 8/9/22

Sustaining attention over long periods of time is a demanding activity, especially when attention is deployed to detect a rare event in a monotonous situation, where people's performance decreases with time on task (i.e., vigilance decrement). Multiple accounts have based their hypotheses about the nature of vigilance decrement on the two main indices of signal detection theory (SDT): d' and β. The SDT framework conceptualizes the observer's ability to differentiate signal from noise (d' or observer's sensitivity) and the internal decision-making process of the observer to provide a response (β or response criterion). In this context, whether or not a progressive decline in sensitivity is due to a loss in the ability to distinguish the target from nontargets has become crucial to disentangling the different explanations. Although hits (i.e., responding "signal" to signal) tend to decrease across time, the frequent use of clearly distinct signal and noise stimuli (such as the digit 3 being the signal and any other digit being noise) leads to a floor effect in false alarms (responding "signal" to noise) that often prevents researchers from observing changes in the response criterion. Thomson et al. (2016) addressed this problem by adding noise stimuli with a more overlapping representation with the target (i.e., lures) and restricting the SDT analyses to those similar-to-signal-noise stimuli. When solving the problem of a floor effect in false alarms, their approach successfully revealed a temporal shift in response bias (becoming more conservative across time) without any loss of sensitivity.

However, because the similarity between noise and signal is typically not manipulated parametrically, it is

Corresponding Author:
Rafael Román-Caballero, Mind, Brain, and Behavior Research Center, University of Granada
Email: rrarroca@ugr.es

not possible to characterize the nature of false alarms and misses with these paradigms; that is, whether a false alarm is made because the noise is perceived as very similar to the signal or because the same perceptual evidence from the noise is categorized as signal because of a criterion shift or an attentional lapse. The same logic can be applied to misses. Thus, we value the critical methodological contribution by McCarley and Yamani (2021) by using continuous distributions of signal and noise instead of binary stimuli. With such an approach, errors due to perceptual difficulty would be more frequent as the noise becomes more similar to the signal, whereas errors due to attentional disengagement would be the same no matter the perceptual signal–noise similarity.

At the analytic level, McCarley and Yamani proposed a new psychometric-curve analysis (see Fig. 1a) that offers three instead of two potential indices of the vigilance decrement: *scale*, associated with sensitivity; *shift*, related to response criterion; and *lapse rate*, proposed as an index of task disengagement or mind wandering. With the addition of the lapse rate, the analysis allows for distinguishing between changes in false alarms and hits that are generalized to any stimulus in the distribution of signal and noise (even in cases where the stimulus category is evident), corresponding with lapse rate, and changes that are specific for near-threshold stimuli, therefore primarily affecting the sensitivity parameter.

Statement of Relevance

Decrements in performance in sustained-attention tasks (i.e., vigilance decrements) are a ubiquitous phenomenon. In the debate about whether vigilance decrement is produced by depletion of attentional resources or by a reallocation of the resources from the primary task toward internal thoughts, the outcomes in the sensitivity parameter from signal–noise discrimination models, such as signal detection theory (SDT), have become crucial evidence. Our analysis with a new vigilance task, the Attentional Networks Test for Interactions and Vigilance—executive and arousal components (ANTI-Vea), and a comparison of our results with those obtained by McCarley and Yamani (2021) show that vigilance decrement can be measured across tasks mainly as increases in response criterion and lapse rate but not always as changes in sensitivity. When a sensitivity change is observed, as in McCarley and Yamani's study, it might instead indicate reduced fidelity of the memory representation of the standard rather than truly reduced perceptual sensitivity. Therefore, whereas psychometric curves improve the analysis of vigilance tasks, they do not support the idea of a loss in perceptual ability regardless of the type of task.

Psychometric Curve in a Different Task

Here, we reproduced McCarley and Yamani's psychometric-curve analysis with their data and with the general database of a vigilance task recently developed by our research group: the Attentional Networks Test for Interactions and Vigilance—executive and arousal components (ANTI-Vea; Luna et al., 2018). With the ANTI-Vea, we observed changes in response criterion and lapse rate but not in the sensitivity parameter. Therefore, McCarley and Yamani's critical finding of a vigilance effect on sensitivity (see Fig. 1a) could be due to their task's particular characteristics rather than the analysis method.

Open Practices

Raw behavioral data and analysis scripts are public available on OSF (https://osf.io/8v6u9/).

Method

Like McCarley and Yamani's task, the ANTI-Vea is a nonbinary vigilance task that makes it suitable for psychometric curves (see Luna et al., 2018, for task details). In most trials (80%), a central arrow is presented flanked by two arrows on each side. In some of these trials (20%; signal), the central arrow presents a substantial displacement along the vertical axis (8 pixels), and participants are instructed to detect these infrequent signal trials by pressing the space bar. In the remaining frequent trials (60%; noise), the five arrows are aligned (although with some noise, ±2 pixels from the midline, so that the maximum displacement among adjacent arrows, including the central arrow and its closest flankers, is 4 pixels); in these trials, participants do not have to press the space bar (they instead have to discriminate the target direction while ignoring adjacent flanker arrows). Those trials constitute the signal and noise trials of an executive vigilance task, as in McCarley and Yamani (2021). In an additional 20% of the trials, a red down counter appears, which participants must stop by pressing any key. These trials are included to measure another component of vigilance (arousal vigilance; see Luna et al., 2018).

We used data from participants who performed the task in a laboratory context (n = 313) and from others who performed an online version at home (n = 303;

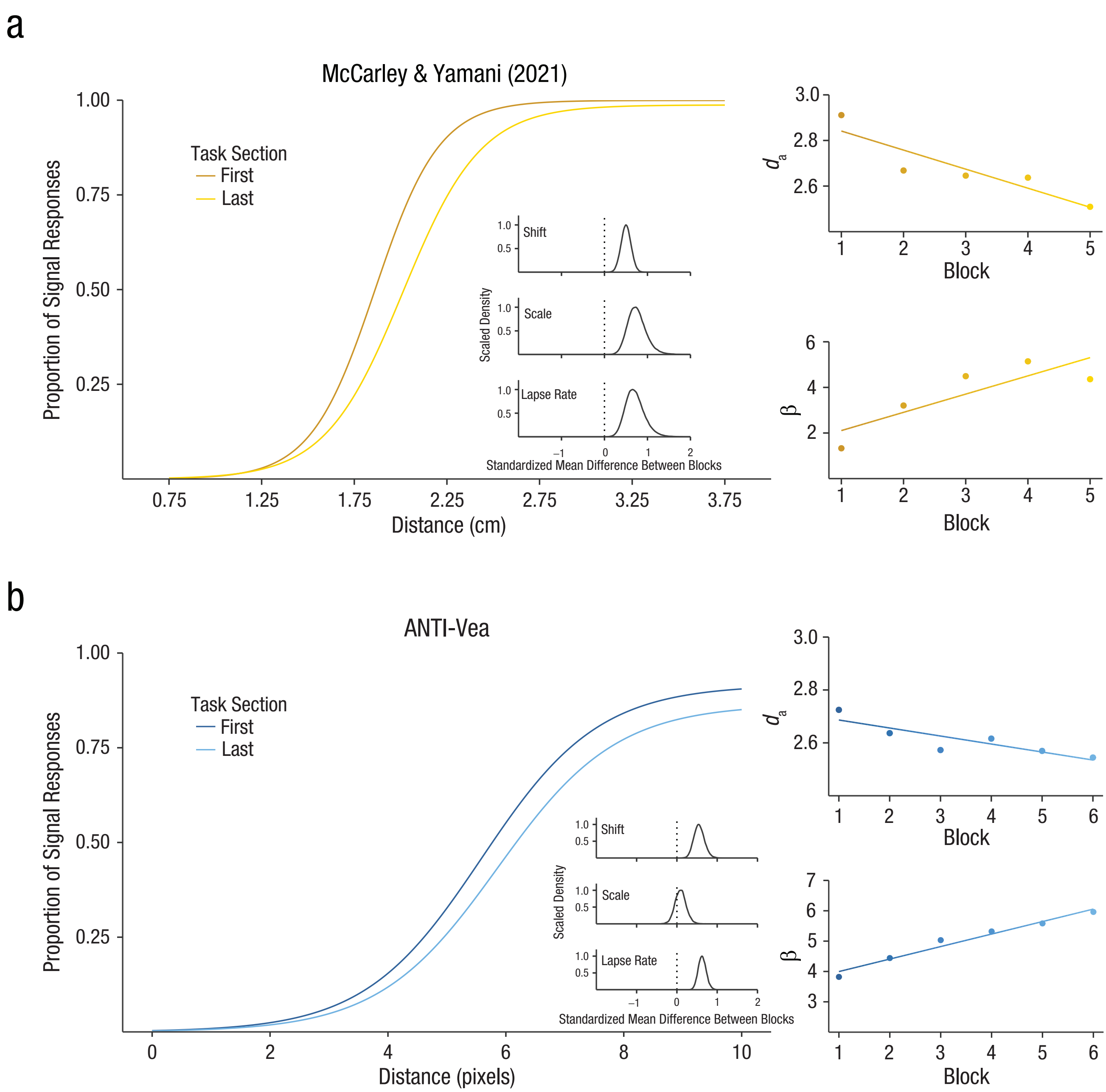

Fig. 1. Psychometric curve for the first and last sections of the task fitted with McCarley and Yamani's (2021) task (a) and with the Attentional Networks Test for Interactions and Vigilance—executive and arousal components (ANTI-Vea; b). Note the changes in the height of the positive asymptote and the horizontal shift of the curve in both tasks, confirmed by the posterior distribution of standardized mean differences in lapse rate and shift between the first and the last sections of the tasks. In contrast, there was a change in scale only in McCarley and Yamani's task. In the ANTI-Vea, whereas the increase in response criterion with the signal detection theory (SDT) approach (β) was replicated in the bias parameter of the psychometric curve, the decrement in the SDT sensitivity parameter (d_a) was absent after analyses took the lapse in the model into account. The results with SDT (d_a and β) are presented on the right side of each panel.

https://osf.io/8v6u9/). There were six blocks of 80 trials each with no rest break between them (the task took ~40 min to complete, including practice trials). As described above, all arrows, flankers, and targets were vertically displaced with a ±2 pixels random variability. In signal trials, the central target was displaced 8 pixels up or down. Therefore, noise trials comprised distances between the target and the two most proximal flankers from 0 to 4 pixels, whereas signal trials involve target–flanker distances from 6 to 10 pixels.

We conducted McCarley and Yamani's original psychometric-curve analysis using the data from the ANTI-Vea and, for comparison, the SDT indices d_a and β. We used a log-linear transformation of hits and false alarms in the SDT analyses to avoid extreme rate values (0 and 1; Verde et al., 2006).[1]

Results

To avoid the influence of participants who misunderstood the instructions or did not perform the task successfully, we excluded those with accuracies below 3 or more standard deviations in noise and signal trials, those with 3 or more standard deviations in the number of no responses, and those who minimized the task screen in the online version. In total, we analyzed the data of 297 participants with the laboratory version and 256 with the online version ($N = 553$). The results for both versions were similar. For the sake of simplicity, we report only the overall analysis on the whole sample.[2]

Consistent with previous applications of the ANTI-Vea in large samples (Luna et al., 2020; Román-Caballero et al., 2021; $N \geq 92$), our results showed a decrement in sensitivity across time on task with SDT analyses, $t(3071.6) = -7.42$, $p < .0001$, along with an increase in response bias, $t(3073.3) = 11.30$, $p < .0001$ (see Fig. 1b). However, the psychometric-curve analysis showed that the putative decrease in d' was due to an increase in the lapse rate rather than a change in sensitivity. Indeed, the parameters that reflected the vigilance decrement in the ANTI-Vea were exclusively horizontal shift and lapse rate, as observed in the posterior distributions of standardized mean differences across blocks—shift: standardized mean change of 0.55, 95% Bayesian credible interval (BCI) = [0.31, 0.83], Bayes factor favoring the alternative over the null hypothesis (BF_{10}) > 10^3; lapse rate: 0.63, 95% BCI = [0.44, 0.83], $BF_{10} > 10^6$; in contrast, scale: 0.09, 95% BCI = [−0.17, 0.37], $BF_{10} = 0.16$.

Response Criterion and Lapse Rate Underlie Vigilance Decrement

The present outcomes suggest that vigilance decrement is robustly associated with a more conservative response criterion and an increase in lapse rate across time. On the other hand, the possibility of a reduction in sensitivity such as the one observed with McCarley and Yamani's task (but not in the ANTI-Vea task) could be specific to the task characteristics. This differential outcome might be explained by the memory demands in McCarley and Yamani's task. In particular, participants had to keep in mind the reference distance (2 cm, the standard) to judge whether the stimulus was a target or not (with an event rate of 40 trials per minute). A decrement in sensitivity is a classic pattern described by Parasuraman (1979), in what he called *successive discrimination tasks* pose memory demands (i.e., participants are required to memorize to respond correctly) and have a high frequency of target presentation (30 targets per minute or more). In such paradigms, the decrement in sensitivity would represent the deteriorated fidelity of the reference-magnitude representation stored in working memory rather than a true decrement in perceptual sensitivity. In the same article, Parasuraman showed that there was no sensitivity decline in tasks without memory demands (i.e., *simultaneous discrimination tasks*), as is the case with the ANTI-Vea: It has a low event rate (15 trials per minute), and executive vigilance trials do not pose memory demands as there is no standard to memorize; participants simply have to detect when the central arrow stands out of the line formed by the other four arrows. Alternatively, another potential factor present in McCarley and Yamani's task that could produce a decline in sensitivity is the perceptual degradation of the target by embedding it in visual noise. Nuechterlein et al. (1983) showed with classic SDT indices that degrading the target could also lead to a decrease in sensitivity across time on task. However, no matter whether the decreased sensitivity observed by McCarley and Yamani is due to working memory demands or perceptual noise, the current analysis of the ANTI-Vea data leads to the conclusion that a decrease in perceptual sensitivity is not always observed with the vigilance decrement, even if the data are analyzed with psychometric curves.

In addition, other methodological critical points should be borne in mind. First, McCarley and Yamani focused on the variation in the positive asymptote of the psychometric curve (lapse rate), which they linked to task disengagement, but the same effect can be assessed in the negative asymptote (i.e., guess rate). Even when time on task does not affect the guess rate, leaving its estimation free (instead of assuming a minimum zero value) could lead to different values for the rest of the parameters and their changes across time. Furthermore, it is relevant for parameter fitting to ensure that performance has reached asymptotic levels at the minimum and maximum stimulus magnitudes (i.e., to ensure that both asymptotes are reached; Prins, 2012). As can be observed in McCarley and Yamani's Figure 3 (left), participants did not show a clear asymptotic level of performance at the minimum distance values (i.e., 0.75 and 1.25 cm). Future researchers applying the psychometric-curve analysis must bear in mind this aspect of the task design.

In conclusion, the vigilance decrement can be better measured with the psychometric-curve analysis proposed by McCarley and Yamani as a more conservative response criterion (curves horizontally shifted to the right) and higher task disengagement across time (indexed by a decrease in right-asymptote curve values;

i.e., decreased correct categorization of the clearest signals). However, taking our results together with McCarley and Yamani's, decreased perceptual sensitivity across time on task (curves with a flatter slope) seems unusual in vigilance tasks. It might emerge only in tasks with high memory demands, perhaps because of the decay of the stored representation rather than decreased perceptual sensitivity.

Transparency

Action Editor: Patricia J. Bauer
Editor: Patricia J. Bauer
Author Contributions

R. Román-Caballero: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Visualization; Writing – original draft.

E. Martín-Arévalo: Conceptualization; Funding acquisition; Investigation; Supervision; Writing – review and editing.

J. Lupiáñez: Conceptualization; Funding acquisition; Investigation; Methodology; Supervision; Writing – review and editing.

Declaration of Conflicting Interests

The author(s) declared that there were no conflicts of interest with respect to the authorship or the publication of this article.

Funding

This work was supported by a predoctoral fellowship from the Spanish Ministry of Education, Culture and Sport to R. Román-Caballero (FPU17/02864); by two research project grants from the Junta de Andalucía and the University of Granada to E. Martín-Arévalo and J. Lupiáñez (PY20_00693 and B-CTS-132-UGR20); and by two research projects from the Spanish Ministry of Science and Innovation to J. Lupiáñez (PID2020-114790GB-I00) and to E. Martín-Arévalo (PID2020-116342GA-I00).

ORCID iDs

Rafael Román-Caballero https://orcid.org/0000-0003-0943-6217
Juan Lupiáñez https://orcid.org/0000-0001-6157-9894

Notes

1. We estimated d_a following the formula $d_a = \sqrt{\frac{2}{1+s^2}} \times \left[z\left(H'\right) - sz\left(F'\right)\right]$, where s is the ratio of the standard deviations of noise and target, and H' and F' are the log-linear transformations of hit and false-alarm rates given $H' = \frac{N_{\text{hits}} + 0.5}{N_{\text{signal}} + 1}$ and $F' = \frac{N_{\text{FAs}} + 0.5}{N_{\text{noise}} + 1}$. We also used the transformation of hits and false alarms (H' and F') for estimating β.

2. Both versions of the ANTI-Vea showed clear changes in horizontal shift and lapse rate. For the online version, we observed standardized mean changes in shift of 0.63, 95% Bayesian credible interval (BCI) = [0.24, 1.15], Bayes factor favoring the alternative over the null hypothesis (BF_{10}) = 36.64, and in lapse rate of 0.56, 95% BCI = [0.26, 0.90], BF_{10} = 170.25 (in contrast, there was inconclusive evidence of a change in scale: 0.49, 95% BCI = [−0.01, 1.34]; BF_{10} = 1.50). For the laboratory version, we observed standardized mean changes in shift of 0.48, 95% BCI = [0.19, 0.82], BF_{10} = 26.44, and in lapse rate of 0.71, 95% BCI = [0.47, 0.97], $BF_{10} > 10^3$ (in contrast, we found evidence against a change in scale: −0.21, 95% BCI = [−0.69, 0.19], BF_{10} = 0.33). See an additional figure comparing the results of both ANTI-Vea versions at https://osf.io/xbs24/.

References

Luna, F. G., Marino, J., Roca, J., & Lupiáñez, J. (2018). Executive and arousal vigilance decrement in the context of the attentional networks: The ANTI-Vea task. *Journal of Neuroscience Methods*, *306*, 77–87. https://doi.org/10.1016/j.jneumeth.2018.05.011

Luna, F. G., Román-Caballero, R., Barttfeld, P., Lupiáñez, J., & Martín-Arévalo, E. (2020). A high-definition tDCS and EEG study on attention and vigilance: Brain stimulation mitigates the executive but not the arousal vigilance decrement. *Neuropsychologia*, *142*, 107447. https://doi.org/10.1016/j.neuropsychologia.2020.107447

McCarley, J. S., & Yamani, Y. (2021). Psychometric curves reveal three mechanisms of vigilance decrement. *Psychological Science*, *32*(10), 1675–1683. https://doi.org/10.1177/09567976211007559

Nuechterlein, K. H., Parasuraman, R., & Jiang, Q. (1983). Visual sustained attention: Image degradation produces rapid sensitivity decrement over time. *Science*, *220*(4594), 327–329. https://doi.org/10.1126/science.6836276

Parasuraman, R. (1979). Memory load and event rate control sensitivity decrements in sustained attention. *Science*, *205*(4409), 924–927. https://doi.org/10.1126/science.472714

Prins, N. (2012). The psychometric function: The lapse rate revisited. *Journal of Vision*, *12*(6), Article 25. https://doi.org/10.1167/12.6.25

Román-Caballero, R., Martín-Arévalo, E., & Lupiáñez, J. (2021). Attentional networks functioning and vigilance in expert musicians and non-musicians. *Psychological Research*, *85*(3), 1121–1135. https://doi.org/10.1007/s00426-020-01323-2

Thomson, D. R., Besner, D., & Smilek, D. (2016). A critical examination of the evidence for sensitivity loss in modern vigilance tasks. *Psychological Review*, *123*(1), 70–83. https://doi.org/10.1037/rev0000021

Verde, M. F., Macmillan, N. A., & Rotello, C. M. (2006). Measures of sensitivity based on a single hit rate and false alarm rate: The accuracy, precision, and robustness of d', A_z, and A'. *Perception & Psychophysics*, *68*(4), 643–654. https://doi.org/10.3758/BF03208765