Individual differences in vigilance: Implications for measuring sustained attention and its
association with other cognitive abilities and psychological constructs

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Abstract

Sustaining attention is notoriously difficult. Typically, when people have to sustain their attention to a single task, their performance deteriorates across time. This phenomenon is usually referred to as the *vigilance decrement*. However, as with most phenomena, there are substantial individual differences in the extent of this effect. That is, some people show more pronounced vigilance decrements than others. Such individual differences can potentially be leveraged to understand the cognitive mechanisms underlying sustained attention. In the present study, we combine linear mixed effects modeling and latent variable analysis to assess individual differences in vigilance and their association with other relevant psychological constructs. We analyzed six published and unpublished datasets and compared findings across studies. These studies used various combinations of working memory, attention control, fluid intelligence, and vigilance tasks. We conclude that vigilance is indeed a trait-level cognitive ability that is meaningfully related to other cognitive abilities, distinguishable yet related to attention control as it is typically measured, and correlates with other state and trait variables.

Keywords: vigilance; sustained attention; individual differences

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For decades, researchers have been interested in sustained attention for both practical and theoretical purposes. Many important occupations require people to maintain vigilant attention to detect and prevent dangerous events, even when such events are few and far between. For example, lifeguards must monitor a swimming area for drowning swimmers. These events are rare, but the early detection of them is crucial to save lives. Similarly, Transportation Security Administration officials must monitor passengers and their belongings for dangerous items. The occurrence of a weapon or explosive device is fleetingly rare, but the officials must vigilantly monitor for such events. An outfielder in baseball might not see a hit come his way for several innings. But any given pitch could result in a line drive in his direction. In that instance, he must react quickly to record the out or prevent a run. Even outside these occupations, everyday tasks - everything from driving a car to reading a book - require sustained attention. From a practical perspective, researchers hope to identify the situations under which sustained attention tends to fail, the factors that promote engagement with an often-monotonous task, and various means to mitigate or avoid sustained attention failures altogether. From a theoretical perspective, vigilance situations provide a glimpse into how the human attention system maintains (or fails to maintain) attention across a period of time. From behavior in these situations, we can start to understand the mechanisms underlying sustained attention and failures therein.

The hallmark of sustained attention research is the finding that performance, whether it be speed of response or accuracy, tends to deteriorate across time. This effect is often referred to as the *vigilance decrement*. In the present study, we focus on this aspect of sustained attention. Considerable debate still exists as to what exactly causes the vigilance decrement. Resource theory posits that draws upon a limited pool of resources that becomes depleted across time (Grier et al., 2003; Warm, Parasuraman, & Matthews, 2008).

Mindlessness theory argues that most sustained attention situations are understimulating, which causes people to disengage from the task as a means of escaping the monotony (Manly, Robertson, Galloway, & Hawkins, 1999; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). More recently, the resource-control theory has argued that vigilance decrements arise because the degree to which people can control their limited resources changes across time (Thomson, Besner, & Smilek, 2015). In the present study, we do not specifically try to test predictions made by these theories. Rather, we examine the extent to which the vigilance decrement is a task-general experience that systematically differs across individuals. This is a crucial assumption underlying all theories regarding sustained attention. If the vigilance decrement is not a task-general phenomenon within an individual, it may not be a meaningful psychological construct. If findings from one task are not be generalizable across tasks, strong theory-testing becomes difficult and the generalizability of theories remains minimal. However, if we can demonstrate that the vigilance decrement is a task-general characteristic of individuals, we can have reasonable assurance that experiments involving different sustained attention tasks are tapping into the same core psychological phenomenon. Furthermore, we can leverage individual differences in the vigilance decrement to test theories about human cognition.

Researchers typically employ several types of tasks to study the vigilance decrement. The first type is a signal-detection task. These tasks present a series of stimuli, and the goal is to distinguish targets from non-targets. In many such tasks, targets occur rarely. Originally, these tasks were developed to mimic scenarios in which monitors must detect a threatening signal embedded within long stretches of non-signals (e.g., radar monitors; Mackworth, 1948). Indeed, this problem was the foundation for vigilance research. In these situations, sensitivity tends to decrease across time. Hits decrease, and sometimes, false alarms increase (but see Thomson, Besner, & Smilek, 2016, for a recent review). A similar type of task reverses the response tendencies. These go/no-go tasks (e.g., the Sustained Attention to Response task - SART; Robertson et al., 1997; Manly et al., 1999), require

participants to respond to the majority of trials while withholding their response to a minority of trials. In these tasks, vigilance decrements manifest as changes in sensitivity and an increase in reaction time (RT) variability (e.g., McVay & Kane, 2009). A third type of task is simple reaction time. In these tasks, participants do not need to make discriminations between targets and non-targets. Rather, they just have to respond as quickly as possible to the onset of a stimulus. Importantly, the onset of the stimulus is unpredictable. Therefore, the participant has to continually engage attention in order to respond quickly on each trial. In these tasks, the vigilance decrement manifests as an increase in RTs across time. The psychomotor vigilance task (PVT; Dinges & Powell, 1985) is an example of this type of task, and it is frequently employed in sleep-deprivation studies (e.g., Doran, Van Dongen, & Dinges, 2001), but also in more basic investigations of sustained attention (e.g., Unsworth & Robison, 2016) and individual-differences investigations of attention control (e.g., Unsworth & McMillan, 2014).

From an individual differences perspective, vigilance decrements can potentially be meaningful. It has been demonstrated that individual differences in the ability to control attention is an important predictor cognitive abilities like reading comprehension and fluid intelligence (McVay & Kane, 2012; Schweizer & Moosbrugger, 2004; Unsworth & Spillers, 2010). The vigilance decrement thus could be an important individual difference. Further, it could be a indicator of clinically-significant attention deficits for particular disorders (e.g., ADHD), it could be used to map the development of attention across childhood and adolescence, and it could help describe age-related cognitive decline. It could also be used to identify individuals who are optimally suited for professions that require a high level of vigilance (e.g., Matthews, Warm, & Smith, 2017). But to be certain the vigilance decrement is a reliable individual difference, we need to empirically demonstrate that this is indeed the case. That is one goal of the present study.

Although prior work has examined individual differences in vigilance/sustained

attention and their association with other theoretically-important psychological constructs (e.g., fluid intelligence, working memory capacity, personality traits, and state variables; Schweizer & Moosbrugger, 2004; Buehner, Krumm, Ziegler, & Pluecken, 2006; Finomore, Matthews, Shaw, & Warm, 2009; Matthews, Warm, Shaw, & Finomore, 2014; Matthews et al., 2017; Shaw et al., 2010; Unsworth, Miller, et al., 2009), there have been some limitations to the methodologies employed. Studies that have used multiple different sustained attention tasks to model vigilance as a task-general ability (Buehner et al., 2006; Schweizer & Moosbrugger, 2004; Unsworth, Miller, et al., 2009) used a summary score from each task in their factor analysis. Therefore these studies did not specifically measure changes in performance across time (i.e., the vigilance decrement). Although aggregate performance measures and changes in performance are likely correlated, they are not necessarily the same index. For example, some people may experience sharp changes in performance across time, whereas others might have relatively good (or poor) performance consistently across the duration of a task. In studies that have specifically examined changes in performance (Matthews et al., 2014; Shaw et al., 2010), these changes have been assessed *within* particular tasks and not correlated *across* tasks. Therefore, the present study combines these approaches to ask four research questions: 1) Do estimates of the vigilance decrement from different types of sustained attention tasks correlate across individuals? 2) When entered into a factor analysis, do these tasks load onto a factor? 3) If these tasks do indeed form a coherent factor, does that factor meaningfully correlate with other psychological constructs (e.g., working memory capacity, attention control, fluid intelligence, personality)? Finally, is vigilance distinguishable from attention control as it has been measured in prior research, or are these abilities virtually identical?

Study 1

The data from Study 1 come from Unsworth, Miller, et al. (2009). In the original study, Unsworth et al. examined correlations among personality traits, fluid intelligence, and executive functioning. Importantly, they included two measures of sustained attention: the PVT and a degraded vigilance (DGV) task. In their reported results, Unsworth et al. did not examine how sensitivity and RT changed across time. Rather, they examined mean RT in minute 10 of the PVT and hit rate in the last block of trials for the DGV task. These two measures did indeed load onto a factor, and this factor correlated with factors for working memory capacity, response inhibition, fluid intelligence, and verbal fluency. Here we reanalyzed the data from the PVT and DGV tasks and specifically measure the vigilance decrement (i.e., change in performance across time).

Method

The sample of 194 undergraduate students from the University of Georgia completed the study in exchange for partial course credit. Participants completed all the tasks during a 2-hr laboratory session.

Tasks

Operation span. Participants solved a series of math operations while trying to remember a set of unrelated letters (Unsworth, Heitz, Schrock, & Engle, 2005). Participants were required to solve a math operation, and after solving the operation, they were presented with a letter for 1 s. Immediately after the letter was presented the next operation was presented. At recall participants were asked to recall letters from the current set in the correct order by clicking on the appropriate letters. For all of the span measures, items were scored correct if the item was recalled correctly from the current list in the correct serial

position. Participants were given practice on the operations and letter recall tasks only, as well as two practice lists of the complex, combined task. List length varied randomly from three to seven items, and there were three lists of each length for a total possible score of 75. The score was total number of correctly recalled items in the correct serial position

Antisaccade. On each trial, a fixation stimulus (***) appeared at the center of the screen. The fixation stimulus remained on-screen for a random interval anywhere from 400 - 1800 ms in 400-ms increments. Then, a flashing cue (=) appeared either on the right or left of the screen. The cue appeared for 100 ms, disappeared for 50 ms, and reappeared for 100 ms. After the cue, a letter (B, P, or R) appeared on the opposite side of the screen for 100 ms. The letter was then masked by an H for 50 ms then an 8 until the participant made a response. Participants pressed a key to indicate which of the three letters appeared. Participants completed 60 trials. The dependent variable was proportion correct (Kane, Bleckley, Conway, & Engle, 2001).

Arrow flankers. Participants were presented with a fixation point followed by a set of arrows directly above the fixation point. The participants' task was to indicate the direction the central arrow was pointing (left or right) as quickly and accurately as possible. There were 50 congruent trials (all arrows pointing in the same direction; <<<<<) and 50 incongruent trials (target arrow was flanked by two arrows pointing in the opposite direction on each side; <<><<). The dependent variable was the RT difference between incongruent and congruent trials.

PVT. On each trial, a row of blue zeroes (00.000) appeared at the center of the screen. After a random time interval from 1 - 10 s (in 500-ms increments), the zeroes started to count up like a stopwatch. The participants' task was to press the spacebar as soon as they noticed the numbers counting. The dependent variable was the RT on each trial (Dinges & Powell, 1985).

Degraded vigilance (DGV). Participants saw a sequence of forward-facing Ds, backward-facing Ds, and 0s in grey font on a patterned background. The participants' task was to press the spacebar anytime they saw a 0 (10% of trials) and withhold their response to the forward- and backward-facing Ds. The dependent variable was a non-parametric estimate of sensitivity (A ; Zhang & Mueller, 2005)

Raven Progressive Matrices. Participants were given a 3 x 3 grid of geometric patterns. The bottom-left piece to the pattern was missing. The participants' task was to select from a set of 8 possible options the geometric pattern that best completed the grid. There were 12 test items. The dependent variable was total number of number correct items (Raven & Court, 1998).

Number series. Participants were given a sequence of numbers. The participants' task was to select from a set of 5 possible options a number that best continued the sequence based on a pattern. After two practice items, participants were given 4.5 minutes to complete 15 items. The dependent variable was total number of correct items.

Results & Discussion

We used R (R Core Team, 2017) for all our analyses. Data were aggregated and transformed using the *dplyr* package (Wickham, François, Henry, & Müller, 2018). The linear mixed effects models were fit using the *lme4* package (Bates, Mächler, Bolker, & Walker, 2015), latent variable models were fit using the *lavaan* package (Rosseel, 2012), and plots were made using *ggplot2* (Wickham, 2016). The manuscript was written as an R markdown document and formatted using the *papaja* package (Aust & Barth, 2018). Figures for factor analyses were made offline. Because we requested data from authors of other studies in addition to analyzing our own unpublished data, we did not make all data publicly available on a database. However the data are available upon request from the first author of each

individual study.

Linear mixed modeling

To estimate the vigilance decrement, we specified a linear mixed effect model with block as a fixed effect and subject as a random effect. Thus, the model fit a separate function to each participant’s data and estimated both a slope and an intercept for each participant. We used the slopes of these functions as our measure of the vigilance decrement for each participant for each task for the analyses of individual differences. Slopes larger in magnitude represent greater vigilance decrements. The equation is shown below:

$$Y_{ij} = \beta_0 + \beta_1 * Block_{ij} + \mu_{0j} + \mu_{ij} * Block_{ij} + e_{0ij}$$

In the equation, Y_{ij} represents the prediction the model makes for the dependent variable at block i for participant j , β_0 is the overall intercept of the model, β_1 is the overall effect of block, μ_{0j} is the participant j ’s intercept, μ_{ij} is the effect of block on the dependent variable for participant j , and e_{0ij} is the error term. The advantage of this model is that it allows for estimation of the effect of block on performance (i.e., the vigilance decrement) at the individual participant level. This allowed us to examine individual differences in vigilance decrements. In each reanalysis, we report the group-level effect of block on performance (β_1) and then use individual slope estimates (μ_j) in our analyses of individual differences.

Reliability

When available, we used reliability estimates from the previously-published datasets (Unsworth & McMillan, 2014, 2017; Unsworth, Miller, et al., 2009). With raw data, we used various methods to assess reliability, depending on the measure. For complex span tasks, we

used Cronbach’s α on average performance for each list length. For the antisaccade task, we used a split-half estimate for accuracy on each hemifield of the screen. For the Raven, number series, and letter set tasks, we used a split-half correlation for odd- and even-numbered items. For flanker and Stroop tasks, we used a formula for computing the reliability of difference score between repeated measurements (Irwin, 1966). For the vigilance decrements, we submitted data for odd- and even-numbered trials to the model separately to compute a split-half correlation.

Table 1 lists descriptive statistics for all measures in the analysis. In our first analysis, we divided performance on both the PVT and DGV tasks into 5 blocks, and we examined performance as a function of block. For the PVT, we used mean RT in each block as the dependent variable. For the DGV task, we used A in each block as the dependent variable (Zhang & Mueller, 2005). A is a nonparametric measure of sensitivity that takes hits, false alarm rates, and their comparative magnitude into account.

At the group level, the linear mixed effects models revealed significant linear effects of block on performance in both the PVT ($b = 12.42$, $t(154) = 14.22$, $p < .01$) and the DGV task ($b = -0.02$, $t(186) = -16.80$, $p < .01$). Thus both tasks demonstrated robust vigilance decrements. These data are plotted in Figure 1.

Our next set of analyses examined individual differences in the vigilance decrements, how these decrements correlated across tasks, and how they correlated with cognitive abilities measured by the other tasks in the session. Table 2 shows a correlation matrix of dependent measures in Study 1. To avoid the analyses being skewed by outlying data points, in this and all subsequent analyses we standardized all measures, then removed data from any scores with z -scores greater than 3 or less than -3. As can be seen in Table 2, the slopes from the PVT and DGV significantly correlated. Thus, people who showed relatively steep vigilance decrements in the PVT tended to show relatively steep vigilance decrements in the DGV task as well.

To see if these tasks formed a coherent factor, we specified a confirmatory factor analysis in which we allowed the antisaccade and flanker tasks to load onto an attention control (AC) factor, the Raven and number series tasks to load onto a fluid intelligence (gF) factor, the slopes from the PVT and DGV to load onto a vigilance (VIG) factor, and we included operation span as a manifest variable. The factors were allowed to correlate with each other and with operation span scores. We used full-information maximum-likelihood for model estimation. The resulting model is depicted in Figure 3. The model fit the data well ($\chi^2(9) = 10.94$, CFI = 0.98, NNFI = 0.96, RMSEA = 0.03, SRMR = 0.03)¹. The model is depicted in Figure 2. Several aspects of the model are notable. The two vigilance tasks significantly loaded onto the VIG factor. The AC and gF measures also formed coherent factors and these factors correlated with each other and with operation span in a manner consistent with prior research (Unsworth & Spillers, 2010). Importantly, the VIG factor significantly correlated with the AC factor, the gF factor, and operation span scores. Participants who showed steeper vigilance decrements tended to show poorer attention control, lower fluid intelligence, and lower operation span scores. However the AC and VIG factors correlated above 1, suggesting these factors represent nearly identical sources of variance.

Therefore we fit a second model in which we allowed the antisaccade, flanker, and vigilance decrements from the PVT and DGV tasks to load onto a single attention (ATTN) factor. This model also fit the data well ($\chi^2(12) = 11.56$, CFI = 1, NNFI = 1.01, RMSEA = 0, SRMR = 0.03).² Indeed, separating vigilance and attention control did not provide a better fit to the model ($\Delta\chi^2(3) = 0.61$, $p = 0.89$). Thus a more parsimonious model with a single attention factor was preferred. This latter model is depicted in Figure 3.

¹ CFI = comparative fit index, NNFI = non-normed fit index, RMSEA = root mean squared error of approximation, SRMR = standardized root mean residual.

² CFI and NNFI are at or above 1 in this context because the chi-square value is below the degrees of freedom in the model.

The results of Study 1 provided several answers to our research questions. First, estimates of the vigilance decrement from two different sustained attention tasks (PVT and DGV) did indeed correlate. Further, when specified to load together onto a factor, they did so. Therefore, it did appear that the vigilance decrement is a reliable individual difference that can be measured across different tasks and modeled at the latent level. Additionally, this latent factor significantly correlated with a fluid intelligence factor and operation span scores, suggesting people who show larger vigilance decrements have lower fluid intelligence and working memory capacity. However, this factor was isomorphic with an attention control factor comprising antisaccade and flanker tasks. A model in which the vigilance decrements, antisaccade, and flanker tasks were allowed to load onto a single factor provided a more parsimonious fit. Thus in this case, vigilance was indistinguishable from attention control as measured by two frequently-employed attention tasks.

Study 2

Data from Study 2 come from Unsworth and McMillan (2014). In the original study, Unsworth and McMillan examined the latent correlations among tendencies to mind-wander, tendencies to experience external distraction, working memory capacity, attention control, and fluid intelligence. Compared to Study 1, Study 2 has several advantageous aspects. First, it has multiple measures of working memory capacity, as opposed to just one measure. Second, it has three measures of attention control and fluid intelligence. Third, thought probes were embedded in the attention tasks, which allows for a measurement of individual differences in the tendency toward task-unrelated thoughts. Finally, Study 2 has a larger sample size than Study 1, which allows for more stable and precise estimates of interindividual relations.

Method

A sample of 241 undergraduate students from the University of Oregon completed the study in exchange for partial course credit. Participants completed all the tasks during a single 2-hr laboratory session.

Tasks

Operation span. See Study 1.

Symmetry span. Participants were required to recall sequences of red squares within a matrix while performing a symmetry-judgment task. In the symmetry-judgment task participants were shown an 8 x 8 matrix with some squares filled in black. Participants decided whether the design was symmetrical about its vertical axis. The pattern was symmetrical half of the time. Immediately after determining whether the pattern was symmetrical, participants were presented with a 4 x 4 matrix with one of the cells filled in red for 650 ms. At recall, participants recalled the sequence of red-square locations in the preceding displays, in the order they appeared by clicking on the cells of an empty matrix (see Unsworth et al., 2009 for more details). There were three trials of each list-length with list-length ranging from 2 to 5 for a total possible of 42. The same scoring procedure as operation span was used.

Reading span. While trying to remember an unrelated set of letters, participants were required to read a sentence and indicated whether or not it made sense (Unsworth et al., 2009). Half of the sentences made sense, whereas the other half did not. Nonsense sentences were created by changing one word in an otherwise normal sentence. After participants gave their response, they were presented with a letter for 1 s. At recall, participants were asked to recall letters from the current set in the correct order by clicking on the appropriate letters. Participants were given practice on the sentence judgment task and the letter recall task, as

well as two practice lists of the combined task. List length varied randomly from three to seven items, and there were three lists of each length for a total possible score of 75. We used the same scoring procedure as we used in the operation span and symmetry span tasks.

Semantic SART. Participants completed a version of a sustained attention to response task (SART) with semantic stimuli adapted from McVay and Kane (2009). The SART is a go/no-go task where subjects must respond quickly with a key press to all presented stimuli except infrequent (11%) target trials. In this version of SART, word stimuli were presented in Courier New font size 18 for 300 ms followed by a 900 ms mask. Most of the stimuli (non-targets) were members of one category (animals) and infrequent targets were members of a different category (foods). The SART had 470 trials, 50 of which were targets. The dependent variable was standard deviation of reaction time for go trials. Thought probes appeared after 60% of target trials. The dependent variables were intraindividual variability in reaction time (RT SD) and sensitivity (A).

PVT. See Study 1. Thought probes appeared after 20% of trials.

Antisaccade. See Study 1. Thought probes appeared after 16% of trials.

Arrow flankers. See Study 1. Thought probes appeared after 40% of incongruent trials.

Stroop. Participants were presented with a color word (red, green, or blue) presented in one of three different font colors (red, green, or blue). The participants' task was to indicate the font color via key press (red = 1, green = 2, blue = 3). Participants were told to press the corresponding key as quickly and accurately as possible. Participants received 15 trials of response mapping practice, and 6 trials of practice with the real task. Participants then completed 135 total experimental trials. Of these trials 67% were congruent such that the word and font color matched (i.e., red printed in red) and the other 33% were incongruent (i.e., red printed in green). The dependent variable was the reaction

time difference between incongruent and congruent trials. Thought probes appeared after 44% of incongruent trials.

Raven Advanced Progressive Matrices. Participants were given a 3 x 3 grid of geometric patterns. The bottom-right piece to the pattern was missing. The participants' task was to select from a set of 8 possible options the geometric pattern that best completed the grid. There were 18 test items. The dependent variable was number correct.

Number series. See Study 1.

Letter sets. In this task participants saw five sets of four letters, and participants were required to induce a rule that applies to the composition and ordering of four of the five letter sets (Ekstrom, Dermen, & Harman, 1976). Participants are then required to indicate the set that violates the rule. Following two examples participants had 5 min to complete 20 test items. A participant's score was the total number of items solved correctly.

Thought probes. The antisaccade, Stroop, flanker, SART, and PVT tasks included periodic thought probes to measure attentional states throughout these tasks. At pseudorandom intervals throughout these tasks, participants would see a screen that said, "Please characterize your current conscious experience." They were given five response options: 1) I am totally focused on the current task, 2) I am thinking about my performance on the task or how long it is taking, 3) I am distracted by information present in the room (sights and sounds), 4) I am zoning out/my mind is wandering, and 5) Other. For the present study, we categorized responses 3 and 4 as task-unrelated thoughts. So the dependent variable was the number of times a participant reported either of these two attentional states during each task.

Results & Discussion

Table 3 shows descriptive statistics for all measures, and Tables 4 - 6 list the zero-order correlations among the measures. In the first analysis, we submitted RT from the PVT and RT SD and A from SART to linear mixed effects models with block as fixed effect and participant as a random effect. The mixed effect models revealed significant linear effects of block on RT in the PVT ($b = 18.01$, $t(212) = 11.38$, $p < .01$) and RT SD in SART ($b = 3.10$, $t(225) = 3.99$, $p < .01$). At the group level, the effect of block on A in the SART was not significant ($b = 0.00$, $t(205) = -1.84$, $p = 0.07$). These data are plotted in Figure 4. Just as in Study 1, we used the slope estimates from the linear mixed models in our analyses of individual differences.

In the next analysis we examined individual differences in vigilance and other cognitive abilities at the latent level. To do so, we specified a confirmatory factor analysis in which we allowed operation span, symmetry span, and reading span to load into a working memory capacity (WMC) factor; the antisaccade, Stroop, and flanker tasks to load onto an attention control (AC) factor; the Raven, letter sets, and number series tasks to load onto a fluid intelligence (gF) factor; the model-estimated slopes from PVT and SART to load onto a vigilance (VIG) factor; and reports of task-unrelated thoughts from the antisaccade, flanker, SART, Stroop, and PVT to load onto a task-unrelated thought (TUT) factor. In order for the model to provide an adequate fit to the data, we allowed the error variances from the Stroop TUT and flanker TUT measures to correlate, as well as the error variances from Stroop TUT and PVT TUT. The model fit the data well ($\chi^2(107) = 160.32$, CFI = 0.93, NNFI = 0.91, RMSEA = 0.05, SRMR = 0.05). Figure 5 shows a graphical depiction of the model. Several aspects are worth noting. First, the vigilance decrements from the two sustained attention tasks loaded onto a factor. Second, this factor significantly correlated with all the other factors. Vigilance positively correlated with the TUT factor and negatively correlated with the WMC, AC, and gF factors. Thus, individuals who showed steeper

vigilance decrements also tended to have lower cognitive abilities in the form of lower WMC, poorer AC, and lower gF. Individuals with greater vigilance decrements also tended to report more TUTs.

To test whether the AC and VIG factors represented identical sources of interindividual variance, as they did in Study 1, we fit a second model to the data. In this model, the antisaccade, Stroop, flanker, and vigilance decrements from PVT and SART were allowed to load onto a general attention factor. Although this model fit the data reasonably well ($\chi^2(111) = 176.33$, CFI = 0.91, NNFI = 0.89, RMSEA = 0.05, SRMR = 0.06), the model that specified separate factors for attention control and vigilance (Figure 5) fit the data significantly better ($\chi\Delta^2(4) = 16.01$, $p < .01$). Therefore vigilance and attention control were distinguishable psychological constructs in this context.

Similar to Study 1, vigilance did indeed arise as a measurable individual difference. Here it was measured by changes in RT in the PVT and changes in RT variability and sensitivity in the SART. These three separate estimates of the vigilance decrement formed a coherent factor, and this factor correlated meaningfully with other cognitive abilities. Finally, this factor was distinguishable from attention control, as allowing all attention measures to load onto a single factor provided a worse fit to the data. This finding is different from that of Study 1, which suggested that vigilance and attention control are one in the same. Here, vigilance and attention control were distinct yet related constructs, sharing about 68% of their variance.

Study 3

The data in Study 3 come from a study examining individual differences in prospective memory. Ball (2015) reported portions of these data. Participants completed measures of working memory capacity, response inhibition (i.e., attention control), sustained attention,

proactive control, reactive control, and prospective memory. Here we restrict our analyses to the measures of working memory capacity, attention control, and sustained attention.

Method

A sample of undergraduate students at Arizona State University completed the study in exchange for partial course credit. Participants completed the tasks during two separate 2-hr laboratory sessions. A portion of participants are missing data for a subset of tasks, as these participants did not return for the second of the two laboratory sessions. We analyzed all available data.

Tasks

Operation span. See Study 1.

Reading span. See Study 2.

Antisaccade. See Study 1.

Arrow flanker. See Study 1.

Psychomotor vigilance (PVT). See Study 1.

Degraded vigilance (DGV). See Study 1.

Results & Discussion

Table 7 lists descriptive statistics for all measures, and Table 8 lists zero-order correlations among the measures. The linear mixed effects models revealed significant effects of block on RT in the PVT ($b = 17.60$, $t(194) = 12.64$, $p < .01$) and A in the DGV ($b =$

-0.02, $t(224) = -18.72$, $p < .01$). Figure 6 shows these data. Just as in the other studies, we used the slopes from the PVT and DGV tasks as measures in the analyses of individual differences.

Next, we examined whether these measures would form a coherent factor in a factor analysis with other measures of cognitive abilities. We specified a confirmatory factor analysis in which we allowed operation span and reading span to load onto a working memory capacity (WMC) factor, arrow flanker and antisaccade to load onto an attention control (AC) factor, and the slopes from PVT and DGV to load onto a vigilance (VIG) factor. The three factors were all allowed to correlate. Figure 3 shows the resulting model. The model fit the data well ($\chi^2(6) = 4.78$, CFI 1, NNFI = 1.02, RMSEA = 0, SRMR = 0.03).³ Importantly, the vigilance decrements from PVT and DGV both loaded significantly onto the VIG factor. The VIG factor significantly correlated with the AC factor, but the correlation between the WMC and VIG factors was not significant. Thus overall, people who showed steeper vigilance decrements in the sustained attention tasks also tended to show poorer attention control.

In Study 1, the attention control and vigilance tasks were best modeled by a single general attention factor. In Study 2, they were best modeled as two separate factors. So we again tested for differentiation between the attention control tasks and the vigilance decrements using model comparison. We fit a model in which the antisaccade, flanker, and vigilance decrements from PVT and DGV were allowed to load onto a single factor. This model also fit the data well ($\chi^2(8) = 11.18$, CFI = 0.98, NNFI = 0.95, RMSEA = 0.05, SRMR = 0.06). However the model that made a distinction between attention control and vigilance provided a slightly yet significantly better fit to the data ($\Delta\chi^2(2) = 6.40$, $p = 0.04$). Therefore, similar to Study 2, there was evidence that vigilance is distinguishable from

³ CFI and NNFI are at or above 1 in this context because the chi-square value is below the degrees of freedom in the model.

attention control as it is more typically measured.

The results of Study 3 answered our research questions, but provided slightly different answers to those questions compared to Studies 1 and 2. Replicating Studies 1 and 2, estimates of the vigilance decrement correlated and formed a coherent factor. This factor significantly correlated with an attention control factor, replicating Studies 1 and 2, but it did not significantly correlate with a working memory capacity factor, which fails to replicate the results from Study 2. Finally, factors representing attention control and vigilance were distinguishable, as a model with these two factors specified separately fit the data better than a model that specified one general attention factor. This finding replicated Study 2.

Study 4

Data from Study 4 come from Unsworth and McMillan (2017). This study examined individual differences in working memory capacity, attention control, fluid intelligence, and attentional lapses in educational contexts. Unsworth and McMillan (2017) had participants complete a battery of cognitive tasks during a laboratory session. Outside the lab, participants completed a diary to record instances of attentional failures. Importantly, the study included two sustained attention tasks (PVT and SART) in the laboratory session. Additionally, the attention tasks included thought probes to measure the tendency to experience task-unrelated thoughts. The data have not been previously reported in the manner in which they were analyzed here.

Method

A sample of 230 undergraduate students from the human subject pool at the University of Oregon completed the study in exchange for partial course credit. All laboratory tasks were completed during a single 2-hr session.

Tasks

Operation span. See Study 1.

Symmetry span. See Study 2.

Reading span. See Study 2.

Antisaccade. See Study 1. Thought probes followed 16% of trials.

Psychomotor vigilance task (PVT). See Study 1. Thought probes followed 20% of trials.

Semantic SART. See Study 2. Thought probes followed 60% of target trials.

Thought probes

During the antisaccade, PVT, and SART, participants were periodically presented with thought probes asking them to classify their immediately preceding thoughts. The thought probes asked participants to press one of five keys to indicate what they were thinking just prior to the appearance of the probe. Specifically, participants saw a screen that said, “Please characterize your current conscious experience.” They were given 5 response options: 1) I am totally focused on the current task, 2. I am thinking about my performance on the task or how long it is taking, 3. I am distracted by sights/sounds or by physical sensations (hungry/thirsty), 4. I am zoning out/my mind is wandering, 5. Other. We summed responses 3 and 4 for each task to create a task-unrelated thinking (TUT) variable.

Results & Discussion

Table 9 lists descriptive statistics, and Table 10 lists zero-order correlations among the measures. The linear mixed modeling indicated a significant linear effect of block on RT in the PVT ($b = 15.62$, $t(219) = 16.44$, $p < .01$) and on RT SD ($b = 6.00$, $t(217) = 6.37$, $p < .01$) and sensitivity (A) in the SART ($b = -0.01$, $t(215) = -5.78$, $p < .01$). Just as in previous analyses, we saved the estimated slope of this function for each task for each participant.

In the next analysis we specified a confirmatory factor analysis in which we allowed operation span, symmetry span, and reading span to load onto a working memory capacity (WMC) factor, the Raven Advanced Progressive Matrices and letter sets to load onto a fluid intelligence (gF) factor, and the model-estimated slopes from the PVT and SART to load onto a vigilance (VIG) factor. We also included antisaccade in the model as a manifest variable. All factors were allowed to correlate. We used full-information maximum-likelihood to estimate the model. The model fit the data adequately ($\chi^2(45) = 84.44$, CFI = 0.91, NNFI = 0.87, RMSEA = 0.06, SRMR = 0.06). Several aspects of the model are worth noting. The slopes from the sustained attention tasks significantly loaded onto a latent factor, and this factor significantly correlated with the antisaccade task, the gF factor, and the TUT factor. However the correlation between the WMC and VIG factors was non-significant.

Overall, Study 4 largely replicated Study 3. People who showed steeper vigilance decrements tended to demonstrate lower fluid intelligence and antisaccade accuracy. Additionally, the vigilance factor significantly correlated with a factor representing task-unrelated thinking. People who showed relatively steep vigilance decrements also tended to report more task-unrelated thoughts during the attention tasks. The vigilance factor did not significantly correlate with working memory capacity, which replicates Study 3. Unfortunately, for this dataset we did not have multiple independent measures of attention control (only antisaccade), so we could not perform a formal test for the distinction between

vigilance and attention control as we could in Studies 1, 2, and 3.

Study 5

The data from Study 5 come from an individual differences investigation of working memory capacity, attention control, and fluid intelligence. The data have not been previously published.

Method

A sample of 254 participants from the human subjects pool at Arizona State University completed the study in exchange for partial course credit. Participants completed all tasks during a single 2-hour session. During three of the tasks (psychomotor vigilance, change-detection, and SART), participants were seated with their head position fixed in a chinrest to allow for eye-tracking data to be collected. The eye-tracker was mounted to the bottom of the computer monitor upon which all tasks were completed. However eye-tracking data were only collected during these three tasks. Participants completed the tasks in the following order: operation span, psychomotor vigilance, Raven Advanced Progressive Matrices, symmetry span, colored-squares change-detection, antisaccade, letters sets, SART, reading span, and number series. A portion of participants did not complete all the tasks for various reasons (e.g., preceding sessions running long, arriving late to the session, taking longer than usual to complete tasks). Sample sizes for individual tasks are shown in Table 11.

Tasks

Operation span. See Study Study 4.

Symmetry span. See Study 4.

Reading span. See Study 4.

Antisaccade. See Study Study 1.

Numerical SART. This task was similar to the semantic SART task used in Studies 2, 4, and 5. But instead of making decisions about animals vs. foods, participants pressed the spacebar anytime they saw any number (single digits 1 - 9) except for the number 3. When they saw the number 3, they were to withhold their response. The numbers appeared in size 18 Arial bold font in the center of the screen for 250 ms, followed by a 2000-ms mask. Participants could make their response any time during the stimulus or mask screen. The numbers 1 through 9 were equiprobable (i.e., no-go trials appeared 11% of the time). After a practice block, participants completed a total of 450 trials.

Colored-squares change-detection. In this task, participants were required to remember the color of items over brief delays. On each trial, a set of 2, 4, or 6 colored squares (30 pixels x 30 pixels each) appeared against a grey background at random locations for 250 ms. Colors were sampled from a set of nine discrete colors (white, black, red, blue, yellow, orange, green, cyan, and pink). Colors did not repeat within a trial. After a 4-s blank, the colored squares reappeared and one square had a black circle around it. The participants' task was to indicate whether this square was the same color or a different color than it was during the initial presentation. Participants pressed a key marked "S" (the F key on the keyboard) for same, and a key marked "D" (the J key on the keyboard) for different. The tested square changed color on 50% of trials. Participants completed 104 trials. Thought probes appeared after 16 trials.

Psychomotor vigilance task (PVT). This task was similar to that used in Studies 1 - 5. The only difference is that a 2-s fixation screen (+++++) preceded each trial, and participants completed 104 trials. Thought probes appeared after 16 trials.

Thought probes

At pseudorandom intervals throughout the change-detection and PVT, participants saw a screen that said, “What were you thinking about in the few seconds preceding this screen?” Response options were 1) I was focused on the current task, 2) I was thinking about my performance on the task, 3) I was distracted by sights/sounds in my environment, 4) I was thinking about things unrelated to the task (e.g., daydreaming), 5) My mind was blank. Responses 3 - 5 were summed for each task to create a task-unrelated thinking variable.

Results

Table 11 lists descriptive statistics for all measures, and Table 12 shows zero-order correlations among the measures. The linear mixed modeling revealed significant effects of block on RT in the PVT ($b = 15.58$, $t(256) = 13.61$, $p < .01$), and on RT SD ($b = 26.41$, $t(233) = 10.65$, $p < .01$) and A in the SART ($b = -0.014$, $t(233) = -8.31$, $p < .01$). Thus the two sustained attention tasks showed robust vigilance decrements at the group level. These data are plotted in Figure 10.

In a confirmatory factor analysis, we allowed operation span, symmetry span, and reading span to load onto a working memory capacity (WMC) factor, Raven, number series, and letter sets to load onto a fluid intelligence (gF) factor, model-estimated slopes from the PVT and SART to load onto a vigilance (VIG) factor, and task-unrelated thoughts from the PVT and change-detection tasks to load onto a task-unrelated thinking (TUT) factor. Antisaccade accuracy was included as a manifest variable. The model fit the data well ($\chi^2(45) = 61.35$, CFI = 0.97, NNFI = 0.95, RMSEA = 0.04, SRMR = 0.04). Figure 11 shows the model. All the factors significantly correlated. People who exhibited steeper vigilance decrements tended to have lower working memory capacity, lower fluid intelligence, and report more task-unrelated thoughts. They also tended to have lower performance on

the antisaccade task.

The results of Study 5 were largely consistent with Studies 1 - 4. The vigilance decrements from the sustained attention tasks correlated and all significantly loaded onto a factor. In this case, the vigilance factor significantly correlated with working memory capacity. This result replicates Study 2. Further, the vigilance factor again significantly correlated with a factor representing task-unrelated thinking, replicating Study 4. But also similar to Study 4, we did not have any independent measures of attention control aside from antisaccade, so we could not perform a model-fit comparison between models with a single general-attention factor and separate factors for attention control and vigilance.

Study 6

The data from Study 6 come from a recent investigation of individual differences in the cognitive, conative, and dispositional correlates of attentional lapses (Unsworth et al., 2019). The study included three measures of working memory capacity (operation span, symmetry span, reading span), two measures of sustained attention (SART and PVT), and one additional attention control task (antisaccade). Participants also completed several tasks that are not analyzed here (choice reaction time, cued visual search, discrete whole-report, and single-object tracking). The study also included self-reports of motivation and alertness after three of the tasks in the session. At the end of the session, participants completed a set of questionnaires to measure personality traits and other dispositional factors. The data have not been reported as analyzed in the present study.

Method

A sample of 358 undergraduate students from the human subject pool at the University of Oregon completed the study in exchange for partial course credit. Participants

completed a battery of working memory tasks, attention tasks, and questionnaires during a single 2-hr laboratory session.

Tasks

Operation span. See Study 4.

Symmetry span. See Study 4.

Reading span. See Study 4.

Psychomotor vigilance (PVT). See Study 1. Thought probes followed 20% of trials.

Semantic SART. See Study 2. Thought probes followed 60% of target trials.

Antisaccade. See Study 1. Thought probes followed 16% of trials.

Thought probes. At pseudorandom intervals throughout the antisaccade, PVT and SART tasks, participants saw a screen that said, “Please characterize your current conscious experience.” They were given 6 response options: 1) I am totally focused on the current task, 2) I am thinking about my performance on the task, 3) I am distracted by sights/sounds in my environment, 4) I am intentionally thinking about things unrelated to the task, 5) I am unintentionally thinking about things unrelated to the task, 6) My mind is blank. Responses 3 - 6 were summed for each task to create a task-unrelated thinking variable.

Self-report measures

After three tasks, participants were asked to report their current levels of motivation and alertness on a 6-point scale. Participants also completed a computerized version of the 44-item Big Five Inventory (John, Naumann, & Soto, 2008), the Boredom Proneness Scale

(Vodanovich & Kass, 1990), the Memory and Attention Lapse portion of the Cognitive Failures Questionnaire (CFQ-MAL; Broadbent, Cooper, FitzGerald, & Parkes, 1982), the Mindful Attention and Awareness Scale (MAAS; Brown & Ryan, 2003), and answered a question about number of hours of sleep they got the previous night.

Results & Discussion

Table 13 lists descriptive statistics for all measures, and Table 14 lists correlations among the measures. The linear mixed models indicated a significant effect of block on RT in the PVT ($b = 13.78$, $t(353) = 15$, $p < .01$), and on RT SD ($b = 7.49$, $t(354) = 8.38$, $p < .01$) and sensitivity (A) in the SART ($b = -0.001$, $t(353) = -3.10$, $p < .01$). These data are plotted in Figure 12. Just as in previous analyses, we saved the estimated slopes of these functions for each task for each participant and used these values in the analysis of individual differences.

Next we included the model-estimated slopes for the effect of block in a confirmatory factor analysis with the complex span, antisaccade, and Stroop tasks. We specified a model in which the complex span tasks loaded onto a working memory capacity (WMC) factor, antisaccade and Stroop tasks loaded onto an attention control (AC) factor, the slopes from PVT and SART loaded onto a vigilance (VIG) factor, and TUT reports from antisaccade, Stroop, and SART loaded onto a task-unrelated though (TUT) factor. We used full-information maximum-likelihood to estimate the model. The model provided an adequate fit to the data ($\chi^2(38) = 102.82$, CFI = 0.89, NNFI = 0.84, RMSEA = 0.07, SRMR = 0.05). The model is depicted in Figure 13.

The results largely replicated Study 4. Again, the vigilance decrements from the PVT and SART formed a factor, and this factor significantly correlated with the WMC, AC, and TUT factors. The WMC and AC factors positively correlated, which is consistent with

Study 3 and prior research, and both of these factors significant correlated with the TUT factor. Thus in Study 6, participants who showed relatively larger vigilance decrements also tended to exhibit lower working memory capacity, poorer attention control, and more task-unrelated thinking. Further, similar to Studies 2, 3, and 4, attention control and vigilance were distinguishable, sharing about 26% of their variance.

Next we examined whether any of the self-report measures correlated with the vigilance factor. In a factor analysis, we included the Big Five personality traits, hours of sleep, and scores on the Boredom Proneness scale, CFQ-MAL, and MAAS as manifest variables. Additionally, we specified latent factors representing motivation and alertness. The three questions regarding motivation loaded onto a factor, and the three questions regarding alertness loaded onto a factor. Error variances between questions following the same task were allowed to load (e.g., antisaccade motivation and antisaccade alertness). The model fit the data well ($\chi^2(200) = 290.32$, CFI = 0.95, NNFI = 0.91, RMSEA = 0.04, SRMR = 0.05). Table 15 shows the correlations between the VIG factors with these added factors/variables. Several correlations are worth noting. First, the VIG factor negatively correlated with both the motivation and alertness factors. Thus people who reported being relatively low in motivation and alertness during the laboratory session tended to show steeper vigilance decrements. Boredom proneness also positively correlated with the VIG factor, suggesting people who are more prone to experience boredom in their daily lives also showed steeper vigilance decrements. Finally, conscientiousness negatively correlated with the VIG factor. Thus people who reported themselves as being more conscientious showed shallower vigilance decrements.

Combined analyses

In our final step, we combined data across the studies to perform a confirmatory factor analysis on all available data. Tables 16 - 18 shows correlations among all measures and the

achieved sample size for each measure. We used full-information maximum likelihood estimation, which takes advantage of all available data, to estimate inter-factor relations. We used standardized measures from each study as the variables. We then fit a model with factors for working memory capacity, attention control, fluid intelligence, vigilance, and task-unrelated thinking. Operation span, symmetry span, and reading span were allowed to load onto the working memory capacity (WMC) factor; antisaccade, Stroop, and arrow flankers were allowed to load onto an attention control (AC) factor; Raven matrices, letter sets, and number series were allowed to load onto a fluid intelligence (gF) factor; the model-estimated slopes from PVT, SART, and DGV were allowed to load into a vigilance (VIG) factor, and TUTs from antisaccade, SART, Stroop, arrow flanker, PVT, and change-detection were allowed to load onto a task-unrelated thinking (TUT) factor. All factors were allowed to correlate. The model provided an adequate fit to the data ($\chi^2(142) = 285.82$, $RMSEA = 0.03$, $SRMR = 0.07$), and it is shown in Figure 14.⁴

One of our central research questions regarded the extent to which vigilance and attention control are distinguishable. To answer this question, we used a model fit comparison between two nested models. We specified a model in which we allowed all the attention measures (antisaccade, Stroop, flanker, PVT, DGV, and SART) to load onto a single factor. However the model with separate factors for vigilance and attention control fit the data significantly better than the model with a single attention factor ($\Delta\chi^2(14) = 68.01$, $p < .01$).

Several conclusions may be drawn from the model. First, the three vigilance tasks formed a coherent factor. Thus, the vigilance decrement does appear to have some task-general interindividual variance that can be modeled at the latent level. Therefore we can conclude that the vigilance decrement is a measurable individual difference. The vigilance factor significantly correlated with other cognitive abilities in theoretically

⁴ *lavaan* did not produce CFI or NNFI values for this model.

meaningful ways. People who showed relatively steeper vigilance decrements tended to exhibit lower working memory capacity, poorer attention control, lower fluid intelligence, and more task-unrelated thinking.

Because these vigilance and attention control factors were distinguishable at the latent level, we next examined the extent to which these factors accounted for shared and unique variance in the other cognitive constructs in the present study. We specified three separate structural equation models in which we allowed vigilance and attention control to predict working memory capacity, fluid intelligence, and task-unrelated thinking, respectively. In the first model (Figure 15), the AC factor had a significant direct path to the WMC factor, but the VIG factor did not. Therefore the shared variance between working memory capacity and vigilance is mostly driven by vigilance's shared variance with attention control. Together, the two factors accounted for 40% of the variance in working memory capacity. In the second model (Figure 16), the AC factor had a significant direct path to the gF factor, but the VIG factor did not. Again, the shared variance between vigilance and fluid intelligence was mostly driven by vigilance's shared variance with attention control. Together, the two factors accounted for 60% of the variance in fluid intelligence. In the third model (Figure 17), the VIG factor had a significant direct effect on the TUT factor, whereas the AC factor did not. Therefore vigilance accounted for a significant portion of variance in task-unrelated thinking over and above its shared variance with attention control. Together, the two factors accounted for 28% of the variance in task-unrelated thinking.

General Discussion

The goal of the present study was to investigate whether the vigilance decrement is a task-general phenomenon that can be measured at the level of individual differences. In prior research, several different types of tasks have been used to measure sustained attention under various conditions. These tasks all show rather robust vigilance decrements – a deterioration

of performance across time. However, to our knowledge, there has not been a systematic investigation of the magnitude of the vigilance decrement on an individual participant level, and whether vigilance decrements correlate across tasks with different dependent variables (e.g., sensitivity of perceptual discriminations, reaction time, reaction time variability).

Below we summarize how the results answered each of our research questions.

Is vigilance a measurable individual difference?

The results yielded a consistent answer to this research question. In Studies 1 and 3, the vigilance decrements from the PVT and DGV correlated and loaded onto a latent factor. In Studies 2, 4, 5, and 6, estimates of the vigilance decrement for PVT and SART correlated with each other and loaded onto a latent factor. In the combined analysis, these estimates all loaded onto a latent factor. Thus, we can conclude with reasonable certainty that vigilance is a measureable individual difference that shows consistency across tasks that measure sustained attention in rather different ways.

How does vigilance relate to cognitive abilities and other psychological constructs?

The fact that vigilance decrements from the PVT and SART correlated and formed a factor allowed us to address our second research question. To this question the results provided a mixture of findings. In Study 1, the vigilance factor significantly correlated with an attention control factor, a fluid intelligence factor, and operation span scores. Subsequent modeling indicated that vigilance and attention control were best modeled by a unitary attention factor. In Study 2, vigilance negatively correlated with working memory capacity, attention control, and fluid intelligence, and positively correlated with task-unrelated thinking. Furthermore, attention control and vigilance were best modeled as separate factors.

In Study 3, vigilance significantly correlated with factors for attention control and fluid intelligence. However in this case, vigilance did not significantly correlate with a working memory capacity factor. Further, attention control and vigilance were best modeled as separate factors. In Study 4, these findings were largely replicated. People who showed steeper vigilance decrements tended to show poorer attention control, lower fluid intelligence, and more task-unrelated thinking. However the correlation between working memory capacity and vigilance was again not significant. In Study 5, the vigilance factor significantly correlated with the other factors and with antisaccade accuracy. In study 6, the vigilance factor again significantly correlated with all other cognitive factors.

Study 6 also included several measures to index personality traits and other dispositions, as well as conative factors like momentary feelings of alertness and motivation to perform the tasks. These data provided some interesting insights. At the dispositional level, people who rated themselves as high in conscientiousness tended to have shallower vigilance decrements. This would be consistent with the conceptualization of conscientiousness as a “socially prescribed impulse control” that facilitates the pursuit of task- and goal-directed behaviors (John et al., 2008, p. 120). Additionally, people who rated themselves high on the Boredom Proneness Scale tended to show steeper vigilance decrements. This is also consistent with the conceptualization of boredom proneness as an aversion to tasks that are monotonous or require a consistent allocation of attention to what feels like a meaningless goal. With regard to conative factors, alertness and motivation both positively correlated with vigilance. Thus people who reported being more alert and more motivated during the experimental session tended to show shallower vigilance decrements. These results indicate that there are individual differences at the cognitive, conative, and dispositional levels that correlate with sustained attention.

In the final confirmatory factor analysis, which collapsed across all five studies, the vigilance decrement negatively correlated with attention control, working memory capacity,

and fluid intelligence and positively correlated with task-unrelated thinking. The relationship between working memory capacity and the vigilance decrement replicates one recent study (Unsworth & Robison, 2019) that also found a negative correlation between the magnitude of the vigilance decrement in the PVT and working memory capacity. In their review of the individual-difference predictors of vigilance, Finomore et al. (2009) identified some factors at the level of cognitive ability, personality traits, pathological symptoms, and state variables. In most cases, they concluded that more evidence is needed to verify the relations between vigilance and these psychological constructs. The present study offers more evidence for such relations. Finomore et al. (2009) found that extraversion occasionally predicts better vigilance, but effect sizes are small. Here, we did not find a relationship between vigilance and extraversion. They found that neuroticism is not a reliable predictor of vigilance, and we also did not observe a relationship between neuroticism and vigilance. Finomore et al. (2009) concluded that conscientiousness may predict vigilance in some situations, and indeed conscientiousness did correlate with the vigilance factor in the present study. Finomore et al. (2009) also found that boredom proneness may predict poorer vigilance, and indeed we found a relationship between the two factors. They reported that the CFQ predicts errors on the SART, but that evidence from other tasks is needed. In the present study, the vigilance factor significantly correlated with CFQ-MAL scores. Additionally, Finomore et al. reported that task-unrelated thoughts predict errors in the SART, but that more evidence from other tasks is needed. In the data analyzed in the present study, the vigilance factor correlated with a task-unrelated thought factor. Finally, Finomore et al. (2009) reported that task-engagement reliably predicts high-workload vigilance tasks. Indeed, we observed a significant correlation between vigilance and motivation factors in the present study. Thus, our results largely corroborate Finomore et al. (2009)'s review on the predictors of vigilance and bring a substantial amount of new data to the picture, especially with regard to the relationship between vigilance and other cognitive abilities.

Are vigilance and attention control the same ability?

Our final research question was whether vigilance is a distinguishable ability from attention control as it has been historically measured. In previous work (Ball, 2015; Unsworth & McMillan, 2014, 2017; Unsworth, Miller, et al., 2009; Unsworth et al., 2019; Unsworth & Spillers, 2010), the DGV task, PVT, and SART have been used to measure attention control, but not in the same manner as the present study. In prior work, researchers have taken summary measures from these tasks to measure attention control. Here, we used a novel approach that combined linear mixed effect modeling and confirmatory factor analysis. Rather than taking a summary measure (e.g., slowest 20% of RT, RT SD, or overall accuracy), we measured the degree to which these measures changed across time for each individual participant. The degree of change (i.e., the vigilance decrement) was thus our dependent variable. When used this way, the data clearly demonstrated that vigilance is not isomorphic with attention control. These abilities are related and share about half of their variance at the latent level. Thus, there is interindividual variance that is shared between vigilance and attention control, but each also have a significant portion of unique variance. Since the abilities were distinguishable, we then examined whether they account for joint or unique sources of variance in the other cognitive factors. Together, the two factors accounted for 40% of the variance in working memory capacity, and the data suggested that the relationship between vigilance and working memory was driven by their shared variance with attention control. A similar situation was true for fluid intelligence. Vigilance and attention control accounted for 60% of the variance in fluid intelligence, and the model suggested that the relationship between vigilance and fluid intelligence is due to their shared variance with attention control. Finally, vigilance and attention control accounted for 28% of the variance in task-unrelated thinking. But in this case, vigilance had a direct effect on task-unrelated thinking, whereas attention control did not. This suggests that a sustained attention ability accounts for variance in the tendency to experience task-unrelated thoughts beyond its

shared variance with attention control. So not only were attention control and vigilance distinguishable at the latent level, they differentially accounted for variance in working memory capacity, fluid intelligence, and task-unrelated thinking.

At the outset of this study, we noted that all theories of vigilance (e.g., resource theory, resource-control theory, mindlessness theory) all rest on the assumption that vigilance tasks tap into a task-general feature of attention. Researchers employ various tasks to study vigilance, and thus rely on this assumption when testing theories regarding vigilance. The present results provide evidence that this may be a sound assumption. But more importantly, vigilance tasks seem to tap into a task-general characteristic of individuals. Thus, the data reviewed here suggest that vigilance is an important individual difference that can be leveraged to study attention in a variety of domains. For example, a task-general measurement of vigilance may be able to identify individuals with clinically-significant attention deficits. From a developmental perspective, vigilance could provide insight into how the human attention system develops across childhood and into adolescence and adulthood. Stretching that timeline further, such a measurement could also be used to identify symptoms of cognitive decline in old age. Finally, individual differences in vigilance could be used to screen individuals who would be particularly suited for positions requiring high levels of vigilance (e.g., air traffic controllers, TSA agents, radar monitors).

Conclusion

The present study used a novel combination of linear mixed effect modeling and latent variable analysis to examine individual differences in the vigilance decrement. The results significantly advanced our understanding of vigilance, the relationship between vigilance and other cognitive abilities, and relations between vigilance and non-cognitive factors. Overall, the data indicated that people with poor sustained attention (greater vigilance decrements) also tend to have poorer cognitive performance in other domains like working memory

capacity, attention control, and fluid intelligence. Additionally, vigilance correlated with aspects of personality (e.g., conscientiousness, boredom proneness) and conative factors like motivation and alertness. This level of analysis opens doors for future research. Although we approached the issue from the angle of cognitive psychology, the present study has diverse implications for various aspects of psychological inquiry. In addition to allowing for strong theory-testing in the cognitive domain, measuring vigilance as an individual difference can be a powerful tool for researchers in clinical, developmental, and human factors domains.

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Table 1

Descriptive statistics for dependent variables in Study 1

	N	Mean	SD	Skew	Kurtosis	Reliability
Operation span	147	60.29	10.00	-0.62	2.65	0.78
Raven	153	9.35	1.45	-0.36	2.76	0.72
Number series	153	9.54	2.28	-0.21	2.78	0.70
Antisaccade	155	0.58	0.17	0.05	2.24	0.84
Flanker	185	111.57	58.17	1.01	4.45	NA
PVT beta	153	12.09	6.28	0.90	3.64	0.94
DGV beta	184	-0.02	0.01	-0.50	2.89	0.92

Note. PVT beta = model-estimated effect of block on reaction times in psychomotor vigilance task; DGV beta = model-estimated effect of block on sensitivity in degraded vigilance task.

Table 2

Zero-order correlations among variables in Study 1

	1	2	3	4	5	6
1. Operation span	–					
2. Antisaccade	.24*	–				
3. Flanker	-.14	-.28*	–			
4. Raven	.08	.17*	-.22*	–		
5. Number series	.26*	.36*	-.34*	.27*	–	
6. PVT beta	-.25*	-.40*	.36*	-.19*	-.34*	–
7. DGV beta	.12	.30*	-.11	.11	.36*	-.25*

Note. PVT beta = model-estimated effect of block on reaction time in psychomotor vigilance task. DGV beta = model-estimated effect of block on sensitivity in degraded vigilance task.

Table 3

Descriptive statistics for dependent variables in Study 2

	N	Mean	SD	Skew	Kurtosis	Reliability
Operation span	236	56.275	11.22	-0.93	3.70	0.77
Symmetry span	238	29.571	6.82	-0.55	2.93	0.71
Reading span	238	51.340	12.61	-0.48	2.77	0.82
Antisaccade	238	0.477	0.11	0.29	2.41	0.76
Flanker	238	106.965	61.80	0.98	4.09	0.60
Stroop	234	157.918	89.33	0.70	3.63	0.58
Raven	240	8.046	2.92	-0.29	2.45	0.70
Letter sets	241	9.154	2.78	0.23	2.67	0.74
Number series	240	8.642	2.40	0.15	2.83	0.70
Antisaccade TUT	241	2.992	3.08	1.09	3.30	NA
Flanker TUT	241	3.772	3.31	0.68	2.57	NA
SART TUT	240	14.950	10.08	0.51	2.65	NA
Stroop TUT	236	3.153	3.74	1.32	4.22	NA
PVT TUT	240	4.958	3.60	0.50	2.69	NA
RT SD beta	220	2.486	4.83	0.84	3.90	0.86
A beta	204	-0.004	0.01	-0.10	2.94	0.60
PVT beta	211	16.935	13.26	1.25	4.72	0.93

Note. SART beta = model-estimated effect of block on standard deviation of reaction times in Sustained Attention to Response Task; PVT beta = model-estimated effect of block on reaction times in psychomotor vigilance task

Table 4

Zero-order correlations among variables in Study 3

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. OSpan	–												
2. SymSpan	.45*	–											
3. RSpan	.46*	.42*	–										
4. Antisaccade	.31*	.26*	.21*	–									
5. Flanker	-.20*	-.28*	-.12	-.18*	–								
6. Stroop	-.16*	-.17*	-.11	-.18*	.09	–							
7. Raven	.22*	.28*	.13*	.17*	-.15*	-.02	–						
8. Letter sets	.29*	.31*	.27*	.27*	-.16*	-.10	.26*	–					
9. Number series	.24*	.28*	.16*	.23*	-.09	-.13	.31*	.35*	–				
10. Anti TUT	-.15*	-.22*	-.13*	-.26*	.05	.06	-.09	-.14*	-.20*	–			
11. Flanker TUT	-.18*	-.17*	-.05	-.12	.02	.00	-.08	-.15*	-.11	.39*	–		
12. SART TUT	-.19*	-.28*	-.35*	-.24*	.09	.02	-.23*	-.27*	-.23*	.43*	.33*	–	
13. Stroop TUT	-.20*	-.07	-.13	.00	-.03	-.02	-.07	-.09	-.07	.33*	.59*	.37*	–
14. PVT TUT	-.16*	-.23*	-.19*	-.09	.15*	-.01	-.11	-.15*	-.21*	.28*	.45*	.45*	.48*

Table 5

Zero-order correlations among variables in Study 3

	1	2	3	4	5	6	7	8	9	10	11	12	13
14. PVT TUT	-.16*	-.23*	-.19*	-.09	.15*	-.01	-.11	-.15*	-.21*	.28*	.45*	.45*	.48*
15. RT SD beta	-.08	-.17*	-.19*	-.21*	.01	.16*	-.01	-.22*	-.16*	.17*	.04	.26*	.10
16. A beta	.17*	.14*	.21*	.19*	.05	-.03	.07	.07	.10	-.22*	-.18*	-.34*	-.24*
17. PVT beta	-.07	-.20*	-.20*	-.26*	.04	.11	-.18*	-.29*	-.15*	.24*	.16*	.31*	.14*

Table 6
*Zero-order correlations among variables
in Study 3*

	14	15	16
14. PVT TUT	–		
15. RT SD beta	.08	–	
16. A beta	-.15*	-.28*	–
17. PVT beta	.29*	.22*	-.18*

Note. PVT beta = model-estimated effect of block on reaction time in psychomotor vigilance task. DGV beta = model-estimated effect of block on sensitivity in degraded vigilance task.

Table 7

Descriptive statistics for dependent variables in Study 3

	N	Mean	SD	Skew	Kurtosis	Reliability
Operation span	203	57.08	14.66	-1.32	4.30	0.89
Reading span	234	52.83	12.15	-0.61	3.15	0.80
Antisaccade	231	0.60	0.18	-0.11	1.83	0.87
Flanker	225	86.57	52.37	0.63	4.27	0.62
PVT beta	193	17.05	12.53	0.88	3.97	0.85
DGV beta	224	-0.02	0.01	-0.47	2.79	0.91

Note. PVT beta = model-estimated effect of block on reaction times in psychomotor vigilance task; DGV beta = model-estimated effect of block on sensitivity in degraded vigilance task.

Table 8

Zero-order correlations among variables in Study 3

	1	2	3	4	5
1. Operation span	–				
2. Reading span	.63*	–			
3. Flanker	-.19*	-.13	–		
4. Antisaccade	.30*	.25*	-.11	–	
5. PVT beta	-.07	.03	.13	-.22*	–
6. DGV beta	.16*	.04	-.07	.32*	-.32*

Note. PVT beta = model-estimated effect of block on reaction time in psychomotor vigilance task. DGV beta = model-estimated effect of block on sensitivity in degraded vigilance task. *correlation significant at $p < .05$

Table 9

Descriptive statistics for dependent variables in Study 4

	N	Mean	SD	Skew	Kurtosis	Reliability
Operation span	219	58.67	10.64	-0.87	3.36	0.76
Symmetry span	221	30.17	6.13	-0.37	2.64	0.65
Reading span	219	56.93	10.76	-0.61	2.84	0.77
Antisaccade	221	0.49	0.12	0.62	2.85	0.95
Raven	222	8.55	2.93	-0.20	2.95	0.67
Letter sets	222	10.34	2.95	-0.10	2.68	0.68
PVT beta	219	15.45	8.76	0.84	3.67	0.87
RT SD beta	215	5.35	6.48	0.94	3.96	0.92
A beta	213	-0.01	0.01	-0.47	3.27	0.47
Antisaccade TUT	215	1.74	2.10	1.33	4.16	NA
SART TUT	219	10.57	8.98	0.84	3.08	NA
PVT TUT	220	3.02	2.84	1.05	3.69	NA

Note. PVT beta = model-estimated effect of block on reaction times in psychomotor vigilance task; RT SD beta = model-estimated effect of block on reaction time standard deviation in Sustained Attention to Response Task; A beta = model-estimated effect of block on sensitivity in Sustained Attention to Response Task

Table 10

Zero-order correlations among variables in Study 4

	1	2	3	4	5	6	7	8	9	10	11
1. Operation span	—										
2. Symmetry span	.30*	—									
3. Reading span	.63*	.32*	—								
4. Raven	.36*	.38*	.27*	—							
5. Letter sets	.26*	.32*	.18*	.35*	—						
6. Antisaccade	.24*	.13	.21*	.23*	.26*	—					
7. PVT beta	-.08	-.14*	.01	-.26*	-.06	-.21*	—				
8. RT SD beta	-.08	-.08	-.12	-.24*	-.24*	-.33*	.23*	—			
9. A beta	.00	.09	.02	.17*	.12	.13	-.20*	-.38*	—		
10. Antisaccade TUT	-.01	-.13	.03	-.03	-.09	-.11	.07	.04	.00	—	
11. SART TUT	-.12	-.15*	-.10	-.18*	-.19*	-.24*	.16*	.36*	-.27*	.34*	—
12. PVT TUT	-.01	-.07	-.02	-.05	.10	-.03	.17*	.02	-.15*	.31*	.44*

Note. PVT beta = model-estimated effect of block on reaction time in psychomotor vigilance task.

SART beta = model-estimated effect of block on reaction time standard deviation in Sustained

Attention to Response Task. TUT = task-unrelated thoughts.

Table 11

Descriptive statistics for dependent variables in Study 5

	N	Mean	SD	Skew	Kurtosis	Reliability
Operation span	247	38.17	7.67	-0.81	3.39	0.78
Symmetry span	253	19.35	5.11	-0.56	2.73	0.65
Reading span	181	32.47	10.83	-0.93	3.59	0.81
Raven	254	8.67	3.42	-0.08	2.50	0.80
Number series	183	8.74	3.11	-0.38	2.56	0.76
Letter sets	251	10.05	3.47	0.13	2.58	0.74
Antisaccade	248	0.40	0.10	0.65	3.11	0.67
PVT beta	249	14.84	7.78	0.71	3.87	0.74
RT SD beta	230	25.25	20.00	0.93	3.61	0.89
A beta	231	-0.01	0.01	-0.53	3.27	0.76
PVT TUT	253	0.48	0.24	0.02	2.38	NA
CD TUT	253	0.38	0.32	0.44	1.97	NA

Note. PVT beta = model-estimated effect of block on reaction times in psychomotor vigilance task; SART beta = model-estimated effect of block on reaction time standard deviation in Sustained Attention to Response Task; CD = change-detection; TUT = task-unrelated thoughts

Table 12

Zero-order correlations among variables in Study 5

	1	2	3	4	5	6	7	8	9	10	11
1. Operation span	–										
2. Symmetry span	.36*	–									
3. Reading span	.47*	.30*	–								
4. Antisaccade	.09	.20*	.20*	–							
5. Raven	.15*	.27*	.20*	.36*	–						
6. Number series	.27*	.31*	.30*	.35*	.47*	–					
7. Letter sets	.31*	.31*	.41*	.36*	.39*	.56*	–				
8. PVT beta	-.04	-.08	-.10	-.15*	-.07	-.10	-.15*	–			
9. RT SD beta	-.15*	-.18*	-.13	-.12	-.25*	-.16*	-.20*	.15*	–		
10. A beta	.04	.07	.19*	.12	.17*	.17*	.08	-.21*	-.32*	–	
11. PVT TUT	-.19*	-.08	-.11	-.16*	-.06	-.14	-.18*	.24*	.20*	-.19*	–
12. CD TUT	-.11	-.10	-.24*	-.16*	-.16*	-.24*	-.19*	.19*	.18*	-.18*	.58*

Note. PVT beta = model-estimated effect of block on reaction time in psychomotor vigilance task;
RT SD beta = model-estimated effect of block on reaction time standard deviation in Sustained
Attention to Response Task.; A beta = model-estimated effect of block on sensitivity in the
Sustained Attention To Response Task; CD = change-detection; TUT = task-unrelated thoughts.

*correlation significant at $p < .05$.

Table 13

Descriptive statistics for dependent variables in Study 6

	N	Mean	SD	Skew	Kurtosis	Reliability
Operation span	355	38.076	7.85	-0.59	2.77	0.68
Symmetry span	356	18.913	5.07	-0.38	2.58	0.63
Reading span	354	37.602	7.97	-0.74	3.10	0.78
Antisaccade	349	0.596	0.15	0.03	2.37	0.83
Stroop	349	147.448	91.76	0.57	3.07	0.59
PVT beta	344	12.479	9.04	1.23	4.92	0.93
RT SD beta	346	7.097	8.06	0.83	4.53	0.90
A beta	344	-0.001	0.00	-2.09	11.78	0.78
PVT TUT	353	0.436	0.30	0.23	2.05	NA
Stroop TUT	354	0.220	0.29	1.39	3.84	NA
SART TUT	354	0.446	0.33	0.23	1.76	NA

Note. PVT beta = model-estimated effect of block on reaction times in psychomotor vigilance task; SART beta = model-estimated effect of block on reaction time standard deviation in Sustained Attention to Response Task.

Table 14

Zero-order correlations among variables in Study 6

	1	2	3	4	5	6	7	8	9	10
1. Operation span	–									
2. Symmetry span	.40*	–								
3. Reading span	.49*	.33*	–							
4. Antisaccade	.18*	.21*	.15*	–						
5. Stroop	-.20*	-.12*	-.12*	-.12*	–					
6. PVT beta	.00	-.11*	-.18*	-.26*	.07	–				
7. RT SD beta	-.01	-.09	-.08	-.12*	-.02	.28*	–			
8. A beta	.06	.15*	.05	.14*	-.04	-.20*	-.30*	–		
9. PVT TUT	-.08	-.14*	-.06	-.13*	.01	.29*	.13*	-.09	–	
10. Stroop TUT	-.13*	-.17*	-.06	-.11*	.06	.14*	.15*	-.11*	.53*	–
11. SART TUT	-.05	-.14*	-.04	-.08	-.03	.13*	.28*	-.21*	.42*	.48*

Note. PVT beta = model-estimated effect of block on reaction time in psychomotor vigilance task. RT SD beta = model-estimated effect of block on reaction time standard deviation in Sustained Attention to Response Task. *correlation significant at $p < .05$.

Table 15

*Correlations between
conative/dispositional variables and
vigilance factor*

	Correlation
Motivation	-.37*
Alertness	-.47*
CFQ-MAL	.18*
MAAS	-.06
Boredom Proneness	.25*
Hours of sleep	-.14
Extraversion	.10
Agreeableness	-.02
Conscientiousness	-.18*
Neuroticism	.07
Openness	-.08

Note. CFQ-MAL = Cognitive Failures Questionnaire - Memory and Attention Lapses; MAAS = Mindful Attention and Awareness Scale; *correlation significant at $p < .05$

Table 16

Zero-order correlations among all variables across studies

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Operation span	–												
2. Symmetry span	.38*	–											
3. Reading span	.53*	.34*	–										
4. Antisaccade	.21*	.20*	.20*	–									
5. Stroop	-.18*	-.14*	-.12*	-.15*	–								
6. Flanker	-.18*	-.28*	-.12*	-.18*	.09	–							
7. Raven	.21*	.31*	.20*	.25*	-.02	-.17*	–						
8. Letter sets	.29*	.32*	.28*	.30*	-.10	-.16*	.33*	–					
9. Number series	.26*	.29*	.22*	.31*	-.13	-.19*	.35*	.44*	–				
10. PVT beta	-.07*	-.12*	-.09*	-.24*	.09*	.16*	-.17*	-.15*	-.19*	–			
11. RT SD beta	-.08*	-.13*	-.12*	-.17*	.04	.01	-.18*	-.21*	-.15*	.22*	–		
12. A beta	.06	.10*	.12*	.14*	-.03	.05	.14*	.09*	.14*	-.20*	-.31*	–	
13. DGV beta	.14*	–	.04	.31*	–	-.09	.11	–	.36*	-.28*	–	–	
14. Antisaccade TUT	-.08	-.18*	-.07	-.20*	.06	.05	-.07	-.12*	-.20*	.15*	.12*	-.12*	–

Table 17

Zero-order correlations among all variables across studies

	1	2	3	4	5	6	7	8	9	10	11	12	13
14. Antisaccade TUT	-.08	-.18*	-.07	-.20*	.06	.05	-.07	-.12*	-.20*	.15*	.12*	-.12*	—
15. Flanker TUT	-.18*	-.17*	-.05	-.12	.00	.02	-.08	-.15*	-.11	.16*	.04	-.18*	—
16. SART TUT	-.10*	-.18*	-.14*	-.17*	-.01	.09	-.21*	-.23*	-.23*	.18*	.29*	-.26*	—
17. Stroop TUT	-.15*	-.14*	-.09*	-.07	.03	-.03	-.07	-.09	-.07	.14*	.13*	-.15*	—
18. PVT TUT	-.11*	-.13*	-.09*	-.11*	.00	.15*	-.07*	-.09*	-.18*	.25*	.12*	-.14*	—

Table 18

Zero-order correlations among all variables across studies

	14	15	16	17
14. Antisaccade TUT	–			
15. Flanker TUT	.39*	–		
16. SART TUT	.39*	.33*	–	
17. Stroop TUT	.33*	.59*	.44*	–
18. PVT TUT	.29*	.45*	.43*	.51*

Note. PVT beta = model-estimated effect of block on reaction time in psychomotor vigilance task; SART beta = model-estimated effect of block on reaction time standard deviation in Sustained Attention to Response Task; DGV beta = model-estimated effect of block on sensitivity in degraded vigilance task; blank correlations indicate places where there were no available pairwise data

Figure 1. Effects of block on a) reaction times in the PVT and b) sensitivity in the DGV task in Study 1 (Unsworth et al., 2009). Error bars represent $\pm$ one standard error of the mean.

Figure 2. Confirmatory factor analysis of attention control (AC), fluid intelligence (gF), vigilance (VIG), and operation span scores in Study 1 (Unsworth et al., 2009). Solid lines indicate significant paths at $p < .05$.

Figure 3. Confirmatory factor analysis of fluid intelligence (gF), a general attention factor (ATTN, and operation span scores in Study 1 (Unsworth et al., 2009). Solid lines indicate significant paths at $p < .05$.

Figure 4. Effects of block on a) reaction time variability and b) sensitivity in the SART, and c) reaction time in the PVT in Study 2 (Unsworth & McMillan, 2014).

Figure 5. Confirmatory factor analysis of working memory capacity (WMC), attention control (AC), fluid intelligence (gF), vigilance (VIG), and task-unrelated thinking (TUT) in Study 2 (Unsworth & McMillan, 2014). Solid lines indicate significant paths at $p < .05$.

Figure 6. Effect of block on a) reaction time in the PVT and b) sensitivity in the DGV in Study 3 (Ball, 2015). Error bars represent +/- one standard error of the mean.

Figure 7. Confirmatory factor analysis of working memory capacity (WMC), attention control (AC), and vigilance (VIG) in Study 2 (Ball, 2015).

Figure 8. Effects of block on a) reaction time variability the SART, b) sensitivity in the SART, and c) reaction time in the PVT (Unsworth & McMillan, 2017). Error bars represent $\pm$ one standard error of the mean.

Figure 9. Confirmatory factor analysis of working memory capacity (WMC), fluid intelligence (Gf), vigilance (VIG), and task-unrelated thinking (TUT) in Study 4 (Unsworth & McMillan, 2017). Solid lines indicate significant paths at $p < .05$. Dotted lines indicate non-significant paths.

Figure 10. Effects of block on a) reaction time variability in SART, b) sensitivity (A) in the SART, and c) reaction times in PVT in Study 5. Error bars represent $\pm$ one standard error of the mean.

Figure 11. Confirmatory factor analysis of working memory capacity (WMC), fluid intelligence (gF), vigilance (VIG), and task-unrelated thinking (TUT) in Study 5. Solid lines indicate significant path coefficients at $p < .05$.

Figure 12. Effects of block on a) reaction time variability in SART, b) sensitivity (A) in the SART, and c) reaction times in PVT in Study 6 (Unsworth, Robison, & Miller, 2019). Error bars represent $\pm$ one standard error of the mean.

Figure 13. Confirmatory factor analysis of working memory capacity (WMC), attention control (AC), vigilance (VIG), and task-unrelated thinking (TUT) in Study 6 (Unsworth, Robison, & Miller, in prep). Solid lines indicate significant paths at $p < .05$.

Figure 14. Confirmatory factor analysis of working memory capacity (WMC), attention control (AC), fluid intelligence(gF), vigilance (VIG), and task-unrelated thoughts (TUT) combined across all studies. Solid lines indicate significant paths at $p < .05$.

Figure 15. Structural equation model in which attention control (AC) and vigilance (VIG) predicted working memory capacity (WMC). Solid lines represent significant paths at $p < .05$. Dotted lines represent non-significant paths.

Figure 16. Structural equation model in which attention control (AC) and vigilance (VIG) predicted fluid intelligence (gF). Solid lines represent significant paths at $p < .05$. Dotted lines represent non-significant paths.

Figure 17. Structural equation model in which attention control (AC) and vigilance (VIG) predicted task-unrelated thinking (TUT). Solid lines represent significant paths at $p < .05$. Dotted lines represent non-significant paths.