Individual Differences in Cognitive Flexibility Predict Performance in Vigilance Tasks

A thesis submitted in partial fulfillment of the requirements

For the degree of Master of Art, in Psychology,

Human Factors and Applied Psychology

By

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Abstract

Individual Differences in Cognitive Flexibility Predict Performance in Vigilance Tasks

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‘Real-world’ vigilance tasks are difficult to perform because they require sustained and divided attention. The present study investigated whether individual differences in a person’s cognitive flexibility, the ability to abandon one cognitive strategy in favor of another, can predict vigilant performance. Sixty-one undergraduate students from California State University, Northridge participated in this study. In Study 1, the Wisconsin Card Sorting Task and an experimenter-created puzzle task measured cognitive flexibility. Vigilance was examined using a multi-screened Clock Task. In Study 2, participants performed either a nine-minute Static or Dynamic Clock task. Results found that two variables of cognitive flexibility predicted signal detection. Cognitive flexibility may become a useful measure of vigilance, and help provide insight for training strategies.
Introduction

Successful performance on surveillance monitoring, air traffic control, lifeguarding and many other vigilance tasks require that employees remain alert and aware of their surroundings (Parasuraman, de Visser, Clarke, McGarry, Hussey, Shaw, & Thompson, 2009; Schwebel, Lindsey, & Simpson, 2007). Multiple factors influence performance during these cognitively demanding tasks include training, workload, and central to this project, individual differences between people's abilities to maintain a vigilant mental state over long periods of time (Endsley & Bolstad, 1994). Vigilance tasks are often challenging because they require that attention be maintained on tasks that humans tend to lose focus on quickly because they are repetitive or uninteresting for long durations of time (See, Howe, Warm, & Dember, 1995; Mackworth, 1969). Although there is a history of research investigating the environmental factors that predict individuals' abilities to perform successfully in vigilance tasks (e.g., Mackworth, 1969), less research has investigated individual differences between peoples' cognitive processes that are involved in successful performance during vigilance tasks. The goal of the present study is to identify individual differences in cognitive flexibility, the ability or propensity to quickly abandon one cognitive strategy in favor of another, and to test whether individual differences in cognitive flexibility predict people's performance during a vigilance task.

Vigilance Tasks

Vigilance is the ability to maintain a heightened state of attention for long periods of time (See et al., 1995). Vigilance tasks typically require that an observer keep watch for a signal, some salient key feature of a visual or auditory display. For example, in
previous work by Mackworth (1969), participants kept watch for an occasionally errant clock tick on an analog clock. Participants in Mackworth’s study were asked to identify errant clock ticks when they occurred, but the relative frequency of non-signals (normal ticks) made detecting such signals difficult. Mackworth found that habituation, an automatic decrease in an innate response as a result of the repetition of non-signals, occurred within thirty minutes of beginning the task and decreased the chance that participants would notice signals.

Vigilance tasks are often classified by three distinguishing characteristics: presentation type (successive and simultaneous), presentation rate (high and low), and by the distinguishing characteristics of the stimuli used as signals or non-signals (Caggiano & Parasuraman, 2004; Parasuraman, 1979; See et. al., 1995). When researchers employ a successive vigilance task, participants are told in advance what form the signal stimuli will be (e.g., an errant clock tick). Participants must then remember the characteristics of that signal and maintain watch for it to appear as successive non-signals are displayed. In contrast, simultaneous vigilance tasks require participants to compare two stimuli at once. For example, to identify when two simultaneously displayed stimuli are different from one another. Typically, research has shown that during simultaneous presentations people maintain higher levels of signal detection over time in comparison with successive presentation types (Parasuraman, 1979).

Perhaps not surprisingly, presentation rates and the types of stimuli used during vigilance tasks also affect participants’ performance. For example, slower presentation rates of signals and non-signals often result in better overall signal detection (See et. al., 1995). Parasuraman and Giambra (1991) found that participants who experience ‘high’
presentation rates, defined as 24 or more stimuli-per-minute, detect fewer signals than when presentation rates are ‘low’ (between 15-24 stimuli-per minute). Researchers have also found that participants detect fewer signals when signals are distinguished from non-sIGNALs on the basis of sensory color, luminosity, or shape changes as opposed to when signals are distinguished from non-sIGNALs on the basis of symbolic or alphanumerical changes (Deaton and Parasuraman, 1993). Still, many vigilance tasks still utilize sensory signals. For instance, it might be difficult to use numbers or letters in an air traffic control screen, thus, researchers have examined what properties in sensory stimuli capture attention. Durlach, Kring, & Bowens (2008) found that red was easier to notice when it disappeared from the visual field. Conversely, blue and yellow were more easily noticed when they appeared on the visual display. Theeuwes (1995) found that when a color suddenly appeared on a visual field (sudden onset), attention was not always captured, but when the color change was followed by a change in luminance, attention was captured. Franconeri, Hollingsworth, and Simons (2005) also suggest that the change in luminance, not the presence of a new object captures attention.

Less is known, however, about how signal detection plays a role in performance during more visually complicated, real-world paradigms when the signal in the vigilance task is human behavior. Parasuraman et al. (2009) conducted one of the first biological motion vigilance tasks which track how motion affects signal detection. Motion studies are unique because they introduce other factors that may affect performance such as the quality of the video. In fact, Parasuraman et al. found that lower quality videos negatively affected performance despite habituation to the task. Although the scope of this study was limited to hand movements, the work underscores the need for research on how people
remain vigilant during ‘real-world’ vigilance tasks (e.g., lifeguarding and security surveillance).

**Sustained Attention during Vigilance Tasks**

Good performance in a vigilance task requires a successful interaction between two types of attentional behavior: *sustained* attention to the vigilance task across long durations of time, and *divided* attention between the various signals that must be identified and the non-signals that must be ignored. Researchers have investigated how participants sustain their attention using vigilance tasks that span long periods of time. Mackworth (1969) utilized a sequential clock task that asked participants to notice when a ticking clock skipped one second ahead. Participants were asked to keep watch for errant ticks, the signals, for a duration of two hours. Mackworth found that participants failed to notice an average of 15% of signals that occurred during the first 30 minutes, and failed to notice an average of 27% of signals in the remaining duration of the task. These findings illustrate the difficulty that most participants have in sustaining their attention during vigilance. To test the external validity of his clock task, Mackworth also tested sonar and radar operators using sonar and radar displays and found similar rates of detection.

Researchers have investigated methods of improving people’s ability to sustain their attention during long vigilance tasks, with mixed results. For example, Mackworth (1969) found that participants who had become less vigilant over time would return to initial signal detection rates following a short break. Mackworth also administered amphetamines to participants, and manipulated the temperature of the rooms in which participants completed vigilance tasks, both of which led to longer periods of sustained
attention. However, many other manipulations designed to prolong sustained attention have been unsuccessful. Feedback about performance during a vigilance task, often referred to as *knowledge of results*, has been shown to be largely ineffective when used to try to improve sustained attention. Mackworth (1969) found that participants who were given knowledge of results while performing a vigilance task (i.e., feedback of correct signal detection, missed signals, and falsely identified signals), quickly habituated to the feedback that was provided. When feedback was introduced in later blocks, participants would temporarily notice more signals. The temporary change in performance may have been due more to the Hawthorne effect, a positive change in the participant’s performance that has *not* resulted from the manipulation of the independent variable. Instead, the increase in performance may have occurred because of the change in the task itself, which caused a temporary performance boost. In vigilance tasks, when knowledge of results is provided in later blocks, it may serve to temporarily recapture the participant’s attention, but other studies suggest that participants become increasingly reluctant to report a signal because they become knowledgeable that signals occur infrequently (Szalma, Hancock, Warm, Dember, and Parsons, 2006).

Yantis and Egeth (1999) found that task irrelevant *singleton features*, a unique quality that make stimuli stand out when they are in the presence of other non-signals, capture attention. For instance, a blue dot in the presence of four red dots would stand out because it is the only blue stimuli. In theory, singleton features could be one way of improving detection rates during vigilance tasks. However, the utility of singleton features would only be manifest when a person’s attention is called to the location where the signal will occur (Rensink, Regan, & Clark, 1997). In many vigilance tasks the
location of an upcoming signal is unknown, thereby limiting the utility of systems that might attempt to employ singleton features to recapture attention in vigilance tasks.

**Divided Attention during Vigilance Tasks**

Although many previous laboratory studies have investigated sustained attention during vigilance tasks, studies have also focused on how well participants are able to divide their attention while performing them. A vigilance task that requires divided attention requires participants to focus on, or quickly cycle between, two or more stimuli at once (Strayer, Drews, and Johnston, 2003). Yet, the focus on one task often comes at the expense of another task. For example, Mackworth (1969) asked participants to anticipate a phone call at the beginning of a successive vigilance task and signal detection rates decreased. More recent studies investigating the tradeoffs associated with driving and conversing (e.g., talking on a cell phone) find that participants take longer to react to a car braking in front of them when a secondary task is simultaneously being performed (Isler & Starkey, 2010; Levy, Pashler, & Boer, 2006). Other performance limitations caused by divided attention are often demonstrated in inattentional blindness studies where a slight change in scenery can go unnoticed by the observer (Simons & Chabris, 1999). Because the participant is focused on a primary task, they fail to notice surprising events that most people would assume would be easily spotted (e.g., a person dressed as a gorilla).

The ability to divide attention successfully may be beneficial during real-world vigilance tasks where observers must attend to many different stimuli simultaneously (e.g., lifeguarding, security surveillance, driving). Researchers have studied methods of improving participants’ abilities to quickly cycle between two tasks. For example, Ho,
Reed, and Spence (2006) utilized vibrations in the seat belt ('vibrotactile' feedback) to help the driver orient attention between the primary and secondary tasks. Levy et al. (2006) found that participants were able to switch between divided attention tasks more quickly when the driver had to manually report the occurrence of the secondary event (i.e., pressing a button) as opposed to vocalizing how often the event occurred. Further, participants were able to divide attention best when presented with auditory rather than visual stimuli suggesting that warning systems should implement auditory modalities.

Although there are cognitive limitations that occur when performing a divided attention task, studies have found that some of the secondary information that goes unnoticed may still be processed at some unconscious level. \textit{Dichotomous listening} tasks require the participant to shadow and repeat a primary message aloud that is broadcast to one ear while unrelated secondary information is being presented in the other ear. The shadowing task serves to block the information that is being presented in the non-attended ear from being consciously processed. Cherry (1953) asked participants to perform a dichotomous task and found that they were \textit{not} able to recognize phrases or words heard in the non-attended ear, but were able to recognize changes in voice, from male to female. Interestingly, only some participants were able to recognize when the information in the non-attended ear had been presented in reverse order, but only by mentioning that there was something 'weird' about the presentation format. Corteen and Wood (1972) conducted a two-part study in which they first conditioned participants to notice city names by lightly shocking them. In the second part of the study, participants performed a shadowing task while their galvanic skin responses were measured. Results indicated that participants were unconsciously responding to the city names that they had
previously been conditioned to respond to in the first part of the study. When asked whether they could recollect information that had been presented in the non-attended ear, participants often did not report remembering any information and made no mention of the city names that had caused their reactions. These studies suggest that information that is not attended to in any deep way may still be processed unconsciously or at some more superficial level.

**Individual Differences in Cognitive flexibility**

Cognitive flexibility is the ability to quickly abandon one cognitive strategy in favor of a second, more optimal, strategy (Scott, 1962). Individual differences in cognitive flexibility have been found to predict successful performance in clinical, developmental, and other applied settings (Adi-Japha, Berberich-Artzi, & Libnawi, 2010; Dennis & Vander Wal, 2010; Lowry & Kim, 2009). Research investigating cognitive flexibility has shown that flexible thinking predicts creative performance, the ability to generate new ideas, and the ability to find multiple ways to use one idea (DeDreu, Bass, Nijstad, 2007; Hirt, Devers, & McCrea, 2008). Bilingual children have demonstrated flexibility in creative tasks that required drawings of non-existent objects (Api-Japha et al., 2010). De Dreu, Baas, Nijstad (2008) found that positive moods (e.g., happiness, elation) often result in more cognitively flexible thinking, which, in turn, can create mental states more conducive to creative thinking. Furthermore, Dreishbach and Goschke (2004) found that positive mood results in flexible thinking and helps people balance goals, stress levels, and pressure. Conway, Cowan, and Bunting (2001) found that the 33% of participants who were most easily distracted, were also most readily able to notice their name being called in a noisy environment, the so-called cocktail party
phenomenon.

Although cognitive flexibility has been found advantageous in other domains, less is known about why cognitive flexibility aids performance or whether it could aid performance in a divided attention task. Endsley and Bolstad (1994) tested individual differences in pilot situation awareness and attention, and found that some pilots had better overall awareness than others when performing a divided attention task. Differences in pilots performing dual tasks can be attributed to experience. One possible explanation for some pilots’ superior performance was an individual difference in their ability to perform divided attention tasks, i.e., better cognitive flexibility.

The Present Study

The goal of the present study is to identify ways that individual differences in flexible thinking may help predict performance on a vigilance task. Cognitive flexibility will first be assessed using Grant and Berg’s (1948) Wisconsin Card Sorting Task (WCST), which has been argued to be a good behavioral assessment of cognitive flexibility (Dennis & Vander Wal, 2009). A second, experimental, measure of cognitive flexibility will also be employed, a puzzle that was developed to focus specifically on the types of cognitive flexibility required for optimal performance in the WCST. Finally, a successive vigilance task, a multi-screened Clock display, will be presented to participants to test their ability to remain vigilant. The main hypothesis being tested is whether participants who display higher levels of cognitive flexibility on the WCST and Puzzle Task will, in turn, perform better on the subsequent Clock vigilance task.
Method

Participants

Sixty-one introductory psychology California State University, Northridge students participated in this study for course credit. Twenty-four participants were male and 37 were female of varying ages ($M = 19.85, SD = 2.98$). Ethnicities also varied (White/Caucasian = 14; Hispanic/Latino = 26; African-American/Black = 7; Asian = 9; other = 5). Participants were able to sign up for the study for course credit.

Materials

**Wisconsin card sorting task.** Participants were administered Grant and Berg’s (1948) Wisconsin Card Sorting Task (WCST), which required them to sort two deck of cards (64 cards in each deck) by an abstract rule known only by the administrator of the test. Participants correctly sorted the cards by matching according to three rules: color, shape, or number. Once the participant sorted ten consecutive cards correctly, the sorting rule changed (i.e., from sort by color to sort by shape), and the participant needed to abandon the old sorting rule in favor of a new one. The task was complete if the participant ran out of cards to sort, or if the participant completed six correct sorting categories.

**Puzzle Task.** A second, experimental, measure of cognitive flexibility was also employed, a puzzle that was developed to focus specifically on the types of cognitive flexibility required for optimal performance in the WCST. In order to solve the puzzle, participants needed to navigate through a maze by matching the shape, shape color, or background color of the adjacent squares in the maze (see Figure 1). Because successful performance required frequent changes in strategy, cognitive flexibility was assessed by
how quickly a participant finished the puzzle. Successful performance of the puzzle
required a total of 17 changes in strategy to succeed.

**Figure 1: The Puzzle Task**

![Puzzle Task Diagram]

**Vigilance Task 1.** A successive vigilance task, a multi-screened Clock display,
was developed to test participants’ ability to remain vigilant for 23 minutes (including a 2
minute break). The Clock display was split into four quadrants; one screen (upper left
corner) was blank, while the three remaining quadrants contained either an analog or a
digital clock (see Figure 2). The bottom right quadrant contained an animated ticking
clock similar to the one that was presented by Mackworth (1969). The upper right digital
clock displayed time ‘12:’ and only changed in the minute’s position. Once the time
reached ‘12:59’, time reset and began at time ‘12:00’. The lower left quadrant contained a
digital clock that displayed changing digits in the hour position. In this case, the ‘:30’
remained constant.
Vigilance Task 2 (Static). Vigilance Task 2, the *static* vigilance task, is identical to Vigilance Task 1 but was only performed for nine minutes (see Figure 3). Signals appeared at an average rate of two signals per minute, for a total of 18 signals.
**Vigilance Task 3 (Dynamic).** Vigilance Task 3 (dynamic) is identical to Vigilance Task 2 (static), except that at the third, sixth, and eighth minute, the location of the three clocks will shift between the four quadrants of the display field (See Figure 4). This *dynamic* shift was intended to force a new search pattern by the participant. Twenty signals were presented in the same order, and on the same clocks, as they were in the static condition, although clocks occupied different quadrants of the display.

**Figure 4: Vigilance Task 3 Before (left) and After (right) Clocks Change Locations**

**Motivation Check.** Following each task (i.e., the WCST, Puzzle, and Vigilance tasks) the question: “How motivated were you to successfully complete the previous task well?” was asked. The response was indicated on a seven point Likert scale where a response of ‘1’ indicated *not very motivated*, a score of ‘4’ indicated average or *no more or less motivated than I would be for any other task*, and a score of ‘7’ indicated *very motivated*.

**Demographics questionnaire and frequency of puzzle check.** Participants were given a demographics questionnaire that asked their age, gender, ethnicity, year in school, and major (See Appendix A). A final question asked participants, “*How frequently do you solve puzzles for enjoyment?*” Their responses were indicated on a seven point Likert
scale where a response of ‘1’ indicated *not very frequently*, a score of ‘4’ indicated *average*, and a score of ‘7’ indicated *very frequently*.

**Design**

**Study 1.** Study 1 is a non-experimental correlational study designed to establish relationships between individual differences in cognitive flexibility (measured by the WCST and the Puzzle) and vigilance performance (measured using Clock task 1). Four variables were used to indicate high or low levels of cognitive flexibility. The first measure of flexibility was time to puzzle completion. In the WCST, flexible thinking was measured by three variables: *failure to maintain set, trials to complete first category,* and *percent perseverative errors* (Figueroa & Youmans, in press). Failure to maintain set measures whether the participant switches set only after making five consecutive correct responses instead of the ten required for the new rule to take effect. Trials to complete first category is the number of moves participants require to complete the first sorting rule of color. Percent perseverative errors measure the percentage of overall sorting decisions whereby participants continue to use the previous sorting rule after the test administrator had informed the participant that the sorting rule was no longer correct.

Vigilance performance was operationally defined as a participant’s average rate of signal detection during the Clock task. There were seven three-minute blocks where six signals were presented at an average rate of one signal per minute. Detection rates were calculated based on the average number of signals that were detected in each three-minute block.

**Study 2.** A between subjects 2 (vigilance task: static, dynamic) x 2 (cognitive flexibility: low, high) quasi-experimental design was used in Study 2. A median split
determined the levels of cognitive flexibility. The dependent variable in this study was the rate of signal detection. Participant’s were able to detect a maximum of 18 signals. Motivation, was also assessed using the questionnaire described in the materials section and included in the analyses where appropriate.

**Procedure**

After obtaining participants’ informed consent, participants either completed a computerized version of the WCST, or completed the Puzzle assessment portion of the study, with the order of the tasks counterbalanced and determined at random. Instructions for the WCST were read by the experimenter out loud, and a practice puzzle was presented where the experimenter completed the first two moves. Participants were informed that there was no time limit to puzzle completion, but were stopped and removed from the study if they did not complete the task after 15 minutes. Participants’ performance on the WCST and the Puzzle Task varied; however, participants completed the cognitive flexibility portion of the study in 25 minutes.

Next, participants completed two Clock tasks. Clock Task 1 was presented with a one-minute practice session in which three signals occurred (at 28, 39, and 51 seconds). When a signal occurred, the Powerpoint remained on the slide for a total of seven seconds. Once two seconds had passed, a red circle and an arrow appeared and showed the participant where the signal occurred. The exact time of the skip was also included in the slide (see Figure 5). Once Clock Task 1 began, the participant was told to say the word “skip” when he or she identified a signal. The experimenter followed along with a stop watch and noted the time on a timesheet (See Appendix B). The experimenter was blind to the location or time that the signal occurred. After nine minutes, the participant
was allowed a two-minute break that was already programmed into the powerpoint. The total duration of Clock Task 1 (including a two-minute break) was 23 minutes. Upon completion of the first vigilance task, participants responded to how motivated they were to complete the task well. Next, participants were randomly selected to perform either the static or dynamic version of Clock task 2. Brief instructions were given to the participant which reminded them to detect the same types of errant ticks by speaking the word “skip” or “skipped”, and the procedure for Clock Task 1 was repeated. Following the vigilance tasks, participants were given a demographics questionnaire, and the debriefing to the study. The total duration of the study was an hour.

**Figure 5: Example of training slide before and after a skip**
Results

The hypothesis for this study is that individual differences in cognitive flexibility will predict vigilance performance and will be demonstrated by performance on the WCST, the Puzzle Task, and by signal detection rates in the three vigilance tasks. Data was screened for multicollinearity to ensure that the variables were not too highly correlated, and none were found to have a higher correlation than 0.6.

Motivation

Pearson $r$ correlations determined whether motivation played a role in successful performance on each task, or if individual differences in performance could be attributed to different levels of cognitive flexibility. It was expected that motivation would not play a role in performance. Only one significant relationship was found between motivation ($M = 6.06; SD = .96$) and time to puzzle completion ($M = 240.28; SD = 182.82$), $r (60) = -0.32, p < .05$. Participants who were motivated to do well on the puzzle completed it more quickly than participants who were not as motivated. Performances on all other tasks were not correlated with motivation (See Table 1).

Table 1

<table>
<thead>
<tr>
<th>Measure</th>
<th>N</th>
<th>M (SD)</th>
<th>Motivation Mean</th>
<th>$r$</th>
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</thead>
<tbody>
<tr>
<td><strong>CF</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Puzzle</td>
<td>60</td>
<td>240.28 (182.82)</td>
<td>6.07</td>
<td>-0.32*</td>
</tr>
<tr>
<td>Trials to 1st Category</td>
<td>61</td>
<td>16.36 (18.61)</td>
<td></td>
<td>0.00</td>
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<tr>
<td>Failure to Maintain Set</td>
<td>61</td>
<td>0.95 (1.19)</td>
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<td>-0.05</td>
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<tr>
<td>% Perseverative Responses</td>
<td>61</td>
<td>12.98 (6.17)</td>
<td></td>
<td>-0.07</td>
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<tr>
<td><strong>Vigilance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clock Task 1</td>
<td>49</td>
<td>18.96 (5.35)</td>
<td>4.48</td>
<td>-0.02</td>
</tr>
<tr>
<td>Clock Task (Static)</td>
<td>28</td>
<td>8.36 (2.74)</td>
<td>3.6</td>
<td>0.17</td>
</tr>
<tr>
<td>Clock Task (Dynamic)</td>
<td>31</td>
<td>7.81 (3.87)</td>
<td>4.3</td>
<td>0.11</td>
</tr>
</tbody>
</table>

*Note. $^*p < .05$
Frequency of puzzles

The frequency of playing puzzles \((M = 3.02; SD = 1.8)\) was assessed using Pearson \(r\) correlations. Only one marginally significant correlation was found between the WCST variable trials to complete first category \((M = 16.36; SD = 18.61)\); \(r(61) = -0.22, p = .09\). This marginal difference suggests that participants who had more experience playing puzzles were able to complete the first sorting category of color in the least amount of moves. No other reliable differences were found (See Table 2).

Table 2

<table>
<thead>
<tr>
<th>Measure</th>
<th>N</th>
<th>M (SD)</th>
<th>Motivation Mean</th>
<th>(r)</th>
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<tbody>
<tr>
<td>CF</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Trials to 1st Category</td>
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<td>61</td>
<td>0.95 (1.19)</td>
<td>3.02(1.8)</td>
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<tr>
<td>% Perseverative Responses</td>
<td>61</td>
<td>12.98 (6.17)</td>
<td>3.02(1.8)</td>
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<td>Clock Task (Dynamic)</td>
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<td>7.81 (3.87)</td>
<td>4.3</td>
<td>.10</td>
</tr>
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</table>

Note. \(\uparrow p < .10\)

Study 1: Clock Task 1

**Stepwise regression.** Study 1 expected to find that individuals with higher levels of cognitive flexibility would detect more signals in Clock Task 1. In order to determine which variables of cognitive flexibility would be most predictive of signal detection in Clock Task 1, a stepwise regression was conducted. The overall regression line was significant, \(F(1, 46) = 6.9, p = .012; R^2 = .13\), indicating that the variable failure to maintain set \((M = .92; SD = 1.15)\) was most predictive of a participants' rate of signal detection \((M = 18.98; SD = 5.4)\). An inverse relationship \((\beta = -.36)\) revealed that
participants who made more failures to maintain set in the WCST, or abandoned the current sorting rule before the new rule had been implemented, detected lower rates of signals in Clock Task 1. No other variables of cognitive flexibility were found to be significant (see Table 3).

Table 3

<table>
<thead>
<tr>
<th>CF Variable</th>
<th>R</th>
<th>Beta</th>
<th>t(49)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Failure to Maintain Set</td>
<td>.13</td>
<td>-.36</td>
<td>-2.63**</td>
</tr>
<tr>
<td>2. % Perseverative Errors</td>
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<td>-.13</td>
<td>-.93</td>
</tr>
<tr>
<td>3. Trials to 1st Category</td>
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<td>-.04</td>
<td>-.3</td>
</tr>
<tr>
<td>4. Puzzle</td>
<td>.03</td>
<td>.03</td>
<td>-0.23</td>
</tr>
</tbody>
</table>

Note. ** p < .05

*Differences between trials.* Individuals with high levels of flexibility were predicted to also have higher signal detection rates (See Figure 6). However, a rapid decline in performance was expected once habituation occurred (indicated prior to 'break'). When given a break from the task, performance was expected to increase. If no break was given to deter habituation after twenty minutes of performing the task, then the individual trait would no longer be beneficial. Conversely, individuals with lower levels of flexibility were expected to follow a similar pattern in habituation, but performance would be maintained at a steadier rate, even, at points, surpassing the performance of high cognitively flexible individuals (in minutes 12-15).

Using the variable failure to maintain set, a mode split determined high and low levels of cognitive flexibility (Low CF = 0 failures, High CF = 1 to 5 failures). Of the 61 participants, 28 participants were placed in the high cognitive flexibility condition and 33 participants were placed in the low cognitive flexibility condition. A one-way ANOVA
determined the average number of signal detection rates separated by the total number of blocks (N = 7). Unlike the expected results, Figure 7 shows that before the break, there is not a reliable difference between the means of high and low cognitively flexible individuals (see Table 4). Rather, their performance is parallel to one another. Also, the actual results of the study show that low cognitively flexible individuals detected more signals per block, which is unlike the interaction in performance that was initially predicted. After the break, however, three marginal differences and one significant difference suggested that low flexible individuals detected more signals that high flexible individuals. In the fourth block, $F(1, 48) = 2.84, p = .10$, marginal differences between the groups are seen. In the fifth, $F(1, 48) = 3.4, p = .07$, and sixth block, $F(1, 48) = 3.45, p = .07$, performance is maintained for both groups, but low flexible individuals continue to detect more signals. Finally, a significant difference was found in the seventh trial, $F(1, 48) = 4.04, p = .05$. Participants who were low in cognitive flexibility, or did not make any failures to maintain set performed best on the second half of Clock Task 1.

Table 4

Clock Task 1 Detection Rates Separated by Block

<table>
<thead>
<tr>
<th>Block #</th>
<th>N</th>
<th>M  (SD)</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>61</td>
<td>3.3 (1.35)</td>
<td>.11</td>
</tr>
<tr>
<td>2</td>
<td>61</td>
<td>2.41 (1.33)</td>
<td>.76</td>
</tr>
<tr>
<td>3</td>
<td>61</td>
<td>2.56 (1.26)</td>
<td>1.21</td>
</tr>
<tr>
<td>4</td>
<td>49</td>
<td>2.82 (1.4)</td>
<td>2.84†</td>
</tr>
<tr>
<td>5</td>
<td>49</td>
<td>2.2 (1.21)</td>
<td>3.34†</td>
</tr>
<tr>
<td>6</td>
<td>49</td>
<td>2.9 (1.54)</td>
<td>3.45†</td>
</tr>
<tr>
<td>7</td>
<td>49</td>
<td>2.98 (1.39)</td>
<td>4.04*</td>
</tr>
</tbody>
</table>

Note. *p < .05 †p < .10
Figure 6: Expected vigilance performance determined by levels of cognitive flexibility (FMS) for Study 1

Figure 7: Actual vigilance performance determined by levels of cognitive flexibility (FMS) for Study 1

Study 2: Clock task 2 Static or dynamic
Stepwise regression. Similar to Study 1, a stepwise regression determined which variable of cognitive flexibility was most predictive of signal detection in Clock task 2 (static and dynamic). The overall regression line was significant, $F(1, 57) = 7.1, p = .01$; $R^2 = .11$ indicating that the variable percent perseverative errors ($M = 12.39; SD = 5.57$) was most predictive of a participants’ combined rate (static and dynamic) of signal detection ($M = 8.08; SD = 3.36$). An inverse relationship ($\beta = -.33$) revealed that participants who made less perseverative errors in the WCST, or abandoned the previous sorting rule in favor of the new one is less moves, detected more signals in Study 2. No other variables of cognitive flexibility were significant (see Table 4).

Table 4

Stepwise Regression: Relationship Between Cognitive Flexibility and Clock Task 2, 3

<table>
<thead>
<tr>
<th>CF Variable</th>
<th>Semipartial</th>
<th>Beta</th>
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<tbody>
<tr>
<td>1. % Perseverative Errors</td>
<td>-.33</td>
<td>-.33</td>
<td>-2.65**</td>
</tr>
<tr>
<td>2. Failure to Maintain Set</td>
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<td>-.19</td>
<td>-1.49</td>
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<tr>
<td>3. Puzzle</td>
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<td>-.16</td>
<td>-1.26</td>
</tr>
<tr>
<td>4. Trials to 1st Category</td>
<td>-.50</td>
<td>-.05</td>
<td>-.36</td>
</tr>
</tbody>
</table>

Note. ** $p < .05$

$F(1, 57) = 7.03 ; \ p < .01$

2X2 ANOVA. Study 2 was predicted to find a main effect of the type of vigilance presentation (Clock Task Static and Clock Task Dynamic) suggesting that participants performing Clock Task Dynamic would detect more signals than participants in the Static condition. An expected interaction was also predicted. Participants who are more cognitively flexible were expected to have higher signal detection rates in the Static-control condition, but not in the Dynamic-experimental condition. It was expected that high flexible participants would not benefit from the moving clocks, which were intended
to capture and refocus attention on the task. Participants who are less cognitively flexible were expected to have higher signal detection rates in the Dynamic-experimental condition but not in the Static-control condition. It was expected that low flexible participants would benefit from the moving clocks, which were intended to force participants to act cognitively flexible. Figure 8 details the layout of the predicted interaction effect between type of vigilance task and level of cognitive flexibility.

Using percent perseverative errors as the measure of cognitive flexibility, a median split was used to determine high and low levels of cognitive flexibility (High CF = 12 or less errors, Low CF = 12 or more errors). Of the 59 participants, 27 participants were placed in the high cognitive flexibility condition and 32 participants were placed in the low cognitive flexibility condition. A 2x2 ANOVA was conducted, and a main effect of level of cognitive flexibility was found ($F(1, 55) = 7.03, p = .01; \eta^2 = .07$), indicating a significant difference between level of cognitive flexibility and rates of signal detection. There was no main effect for the type of clock task ($F(1,55) = .06, p < .05; \eta^2 = .00$) suggesting that the differences between the clock tasks did not affect signal detection. Lastly, there was not a significant interaction ($F(1, 55) = .76, p < .05; \eta^2 = .01$). To further explore where the differences between the high and low flexible groups occurred, t-tests were conducted. No significant difference was found between high ($M = 8.59, SD = 2.69$) or low ($M = 7.6, SD = 2.55$) cognitively flexible individuals in the static condition, $t(26) = 1.13, p > .05$. However, a marginal difference was found between high ($M = 9.13, SD = 3.62$) and low ($M = 6.65, SD = 3.67$) cognitively flexible individuals in the dynamic condition, $t(29) = 1.93, p = .06$. The actual results of Study 2 found a marginal difference between high cognitively flexible individuals and low cognitively
flexible individuals. Conversely to what was expected, participants with high flexibility seemed to benefit from the experimental manipulation, while participants with low flexibility decreased in their rate of performance.

Figure 8: Expected Interaction for Study 2

![Figure 8: Expected Interaction for Study 2](image)

Figure 9: Actual Interaction for Study 2

![Figure 9: Actual Interaction for Study 2](image)

**Differences by trial.** A one-way ANOVA determined the average number of signal detection rates separated by the total number of trials. Figure 10 outlines the
average rates of signal detection between trials for the static and dynamic conditions, and across both levels of flexibility. In the static condition, no significant differences were found between level of flexibility and average rate of detection between the first, $F(1, 25) = 1.46, p > .05$, second, $F(1, 25) = 1.6, p = .22$, and third blocks, $F(1, 25) = .29, p = .6$. Participants' level of cognitive flexibility did not play a significant role in signal detection for the static condition. In the dynamic condition, there was a significant difference in block 1, $F(1, 30) = 5.04, p < .05$, however no other reliable differences were found in block 2, $F(1, 30) = 4.6, p > .05$, or block 3, $F(1, 30) = 2.1, p = > .05$. These results suggest that participants with high levels of flexibility were only outperformed their counterparts in the first block of the dynamic condition.

Figure 10: Performance across trials for Clock Task 2
Discussion

The present study sought to identify how individual differences in cognitive flexibility could predict vigilant performance. A two-part study was presented, and participants completed various tasks that determined their level of cognitive flexibility and rates of signal detection. Study 1 was expected to find that individuals with higher levels of cognitive flexibility would initially detect more signals, but as time progressed detection rates decreased. Individuals who were less cognitively flexible were expected to have steadier rates of detection. Study 2 hypothesized that participants in the Dynamic condition, which forced participants to actively switch from screen to screen, would be able to maintain vigilance better than those in the static condition. Participants with low levels of cognitive flexibility were expected to receive the most benefit from the dynamic display.

Study 1

The hypothesis for Study 1 was not confirmed. Individuals with higher levels of cognitive flexibility did not make more signal detection rates for the vigilance task, Clock Task 1. Instead, participants who demonstrated lower levels of cognitive flexibility, indicated by the variable failure to maintain set, outperformed their counterparts. The main finding of Study 1 is that prior to the break, both sets of individuals followed an almost parallel pattern of signal detection. In the first block, both groups detected an almost identical amount of signals. However, rates of signal detection decreased rapidly from block 1 to block 2, yet performance was maintained in the third block for both groups. Following the break, the same pattern is shown between both groups (i.e., higher rates of detection that rapidly decrease, and increase steadily once again). However, the
difference in rates of signal detection between low cognitively flexible individuals and high cognitively flexible individuals is strengthened, and those in the low cognitively flexible condition detected significantly more signals.

Previous literature (e.g., Mackworth, 1969) has stated that breaks help a participant reset their focus on the vigilance task. However, in this study not all participants’ performance “reset” after the break. In fact, there were significant differences in performance between groups after the break. Participants who did not make any failures to maintain set in the WCST, or who did not abandon the new sorting rule before the experimenter’s cue, were found to detect more signals following the break. This finding may be explained if we look at failure to maintain set. Failure to maintain set has been associated with high levels of cognitive flexibility, particularly with individuals that have difficulty maintaining their attention (Kaland, Smith, & Mortensen, 2008). Thus, it may not be surprising that following the break, individuals who were considered low in cognitive flexibility were able to reset their attention on the task.

Participants who failed to maintain set in the WCST (i.e., high cognitive flexibility) may have done so in anticipation of the next sorting rule, thus demonstrating a very high ability to think flexibly. However, the signals that occurred in the Clock Task were in random order and followed no particular pattern. Perhaps these participants attempted to use their ability to think actively in the first three blocks and thus, no significant differences were found between the groups. These participants may have begun to feel bored or frustrated particularly once they realized that they would have no gain from their ability to think strategically. Once the break was over, these particular
participants may have drifted from the task and may have begun to daydream or focus their attention elsewhere, which may have led to lower performance.

Another explanation regarding the differences in performance may be due to motivation to perform the task well. However, this study did not find reliable differences between motivation and performance on the WCST, suggesting that despite participants’ motivation to perform the task well, successful performance still varied. For example, the individual who failed to maintain set may have done so because he or she momentarily looked away and forgot the new sorting rule, but immediately corrected the mistake; or, he or she may have regressed back to the old sorting rule (Floresco, 2011), all of which are components of cognitive flexibility, and not necessarily a lack in motivation.

**Study 2**

Study 2 was conducted in an effort to see if an experimental manipulation that makes a system cognitively flexible may in fact aid individual performance. It was expected that participants with low cognitive flexibility would gain an advantage by forcing them to think flexibly, however, the dynamic task had mixed results. Instead, marginal differences were found in the dynamic condition, suggesting that highly flexible participants had overall higher rates of signal detection. As expected, no differences were found in the static conditions, and both high and low flexible participants detected similar amounts of signals.

In Study 2, high cognitively flexible individuals showed trends that outperformed low flexible individuals overall. Unlike Study 1, cognitive flexibility was dichotomized using the variable percent perseverative errors. This variable found that participants who were able to switch to the next sorting rule with the least amount of moves (i.e., 12 or
less) were more cognitively flexible. Results suggested that participants were at an advantage if they demonstrated high levels of cognitive flexibility.

Another significant difference was found in Block 1 for the dynamic condition. After participants performed the 21-minute vigilance task, high cognitively flexible individuals seemed to transition easily to the next task, indicated by their higher detection rates. However, following the first trial, participants in the dynamic condition rapidly declined in their performance while participants in the static condition maintained a steadier rate of performance. A possible explanation for this trend is that the experimental manipulation did not work. In fact, the manipulation did not begin until the second block of the dynamic task. At that point, participants had been performing the vigilance task for about 27 minutes and may have been accustomed to the previous position of the clocks. As shown in Figure 10, performance only continued to decline from block 2 to block 3 in the dynamic condition. If participants were introduced to the dynamic system from the beginning, other benefits may have been found. Future studies may continue to make between groups comparisons by randomly assigning participants to a dynamic task only and a static task only.

**General**

Between Study 1 and Study 2, a deeper understanding has been provided for individual differences in cognitive flexibility. Although in Study 1, high levels of cognitive flexibility hurt performance, in Study 2, the results were reversed. In Study 1 participants who did not fail to maintain set in the WCST were found to be maintaining their attention best throughout the task, thereby achieving higher rates of signal detection. Clock Task 1 was divided into two parts in an effort to make the task more manageable.
Still, benefits in cognitive flexibility may not have been seen following the break because participants were conscious that Clock Task 1 was a long task. Their ability to be flexible was therefore not transferred onto the second portion of Clock Task 1. Participants who were considered to be low in flexibility (or who maintained set throughout the entire WCST), capitalized on their ability to maintain focus.

Conversely, the results of Study 2 suggest advantages to having high levels of cognitive flexibility. In fact, between Clock Task 1 and Clock Task 2 (static or dynamic) the only break that participants had was the switch between the two Powerpoint programs that had been minimized on the computer. After a quick reminder of the instructions, participants, on average, had a one-minute break between the two tasks as opposed to the two minute break that was implemented in Clock Task 1. Perhaps, the knowledge of performing a completely new task, allowed the benefits of cognitive flexibility to be seen, and participants’ ability to make less errors of perseveration (i.e., high cognitive flexibility) was a significant predictor of signal detection in the first block of the dynamic task. Therefore, although individual differences in cognitive flexibility did not aid participants in dividing their attention within the task, it seems to have helped individuals switch between the tasks more easily.

Further, cognitive flexibility appears to be a complex individual difference that cannot be distinguished nor identified solely by one variable, which is perhaps why it is so difficult to categorize or measure. The results of these two studies suggest that flexibility may hinder or aid vigilant performance. It could be that this ability is on a spectrum, and individuals can use it according to their need. Or perhaps an individual has a certain level of flexibility that may not be activated or deactivated. Otherwise, we may
have seen an opposite pattern of performance for in Clock Task 1. Participants who failed to maintain set in the WCST may have instead outperformed those participants that were better at sustaining their attention.

**Limitations and Future Studies**

Many of the limitations in this study were created because of ambiguity about which of the four variables to select in order to determine which participants were cognitively flexible and which were not. In the analysis reported here, stepwise regression was used to determine which variable best predicted overall vigilance. However, stepwise regression finds relationships without considering if the relationships are theoretically grounded, which can lead to elevated rates of Type I error. For example, although failure to maintain set was the best predictor of vigilance in Study 1, it is unclear whether failure to maintain set is reflective of cognitive flexibility, or some other cognitive measure that might also predict high levels of vigilance (e.g., interest in the task, motivation, etc.).

A second limitation related to the use of stepwise regression to determine which variable of cognitive flexibility to select was the use of overall signal detection, across all seven blocks in Study 1 and three blocks in Study 2. By looking at the relationship between aggregate signal detection and the four variables of cognitive flexibility, possible interactions between the blocks as time passed and the level of cognitive flexibility would be undetectable by the stepwise regression. As seen in Figure 6, people with high cognitive flexibility were expected to begin the vigilance task with an advantage over low cognitive flexibility participants, but would lose the advantage over time. To the extent to which this was true, the use of overall signal detection as the main dependent variable
would actually cause the stepwise regression to overlook the variables that predicted this interaction. Future studies should utilize statistical techniques that are sensitive to interactions between time, cognitive flexibility, and vigilance.

Overlooking limitations created by the use of stepwise regression, another limitation of the study was the manner in which the participants were dichotomized using the variable failure to maintain set in Study 1. In Study 1, participants who did not make any failures to maintain set on the WCST were categorized as “low” in flexibility and participants who made one or more failures were categorized as “high” in flexibility. Previous studies have shown that individuals with extreme cases of cognitive flexibility fail to maintain set between 1.2 to 2 times per session, while normal populations make between .6 to .99 failures (Kaland et al., 2008; Mullane & Corkum, 2007). Although the average participant failed to maintain set roughly 0.91 times per session in this study, a distinction had to be made between high and low flexibility and for purposes of creating groups with equal sample sizes, a mode split was utilized. The mode split created a low flexible group who never failed to maintain set and compared it against a group that always failed to maintain set at least one time. This dichotomous outcome may further call into question the conceptual validity of failure to maintain set as a viable measure of cognitive flexibility.

A third limitation related to the method used to identify variables of cognitive flexibility that predicted vigilant behavior was that the variable that was most predictive in Study 1, failure to maintain set, was different than the variable that was found to be most predictive in Study 2, percent perseverative errors. One problem with this outcome is that it remains unclear which variable is best associated with vigilant behavior, or in
fact, if either variable is actually a reliable measure of cognitive flexibility. Because the variables were not the same from Study 1 to Study 2, it was unclear whether the same participants who were determined to be low in flexibility in Study 1, were the same participants who were determined to be low in flexibility in Study 2. And in fact, an a priori analysis found that roughly half of the participants were classified differently in Study 2 than they had been in Study 1. The combination of different variables and different classifications of participants makes conclusions drawn from comparisons between Study 1 and Study 2 tenuous. For example, people who were classified as high in flexibility performed worse than those classified as low in the first blocks in Study 1, a pattern that was reversed in Study 2.

A final limitation of this study concerns participants’ motivation to successfully perform the vigilance tasks that they were presented with. Vigilance tasks that are completed in a laboratory setting differ from ‘real-world’ vigilance tasks because participants in laboratory settings may be much less motivated to remain vigilant. Researchers have identified various extraneous factors related to “real-world” vigilance tasks (e.g., stress, workload, levels of training, experience, and age) that may affect signal detection rates (e.g., Szalma et al., 2006). In this study, participants may have begun the task in earnest, but lost motivation once the length of the study became apparent. Additionally, participants in this study were not identifying signals of any great importance the way they might be asked to in a ‘real-world’ vigilance task (e.g., dangerous objects in airport luggage screening). This combination of factors may have affected the motivation of participants, challenging the external validity of the findings.
In general, many of the limitations of this study stem from the use of the WCST as a measure of cognitive flexibility. The WCST has over fifteen dependent variables that serve to measure abnormalities in the frontal lobe. Thus, the output includes data that is irrelevant to measures of cognitive flexibility. As a result of the multiple dependent variables of the WCST, a new measure of cognitive flexibility was created, the Puzzle Task. And yet, because cognitive flexibility was measured by time to completion in the Puzzle Task, it may not have been indicative of the ways in which people think flexibly that the WCST might detect. Therefore, future researchers may wish to implement computer-based versions of the puzzle that are able to measure failures to maintain set, perseverative errors, and trial to complete first category, variables that are similar to those measured by the WCST.

In addition to improvements in the Puzzle Task, future studies may wish to incorporate eye tracking to help clarify which variables of cognitive flexibility are corresponding with the physical behaviors of participants. Assuming that eye tracking is an indirect measure of attentional focus and assuming that cognitively flexible people demonstrate flexibility through eye saccades, eye-tracking studies put to rest arguments about which of the many different potential variables are, in fact, measuring cognitive flexibility. Eye-tracking studies may also provide insight into how motivation is affecting performance. For example, if a participant is failing to maintain set in the WCST, it could be because he or she is unmotivated to perform the task or because he or she is attempting to anticipate the next sorting rule. In an eye-tracking study, researchers can determine whether the participant is daydreaming or anticipating the whereabouts of the
next signal, and on the basis of these observations clarify if failure to maintain set is the measure of cognitive flexibility that some describe it as.

In addition to potential clarifications about which variables are measuring cognitively flexible behaviors, eye tracking may be useful for detecting the ratio of signals to overall stimuli in a ‘real-world’ vigilance task. In the present study, one signal occurred for every 180 stimuli presented. This ratio was chosen to better match the ratio of signals to overall stimuli in ‘real-world’ vigilance tasks (e.g., cameral surveillance). However, eye-tracking studies may help determine the limit of how many signals an individual can realistically detect compared to overall rates of stimuli presentation.

Finally, eye-tracking studies may be useful in determining whether the physical behaviors of participants with low and high levels of flexibility are similar. This is important because it is unclear at this time whether individuals with low and high levels of flexibility have different patterns of visual behavior alone, or whether they have similar patterns of visual behavior but different mental strategies that accompany them. One possibility is that eye-tracking studies will reveal that individuals with low flexibility are actively engaged in scanning the visual field, but perseverating on the same search strategy. Another possibility is that individuals with low flexibility fail to continue to engage in visual search, but rather, come to focus on only one area of the visual field. Determining which is true may have important consequences on the development of potential methods for improving vigilant behavior.

Perhaps the most important theoretical question that future studies should address concerns the very nature of what is means to be cognitively flexible. The research reported here and other research would suggest that there are at least two possible
mechanisms underlying cognitively flexible behavior. One possibility is that humans who are cognitively flexible are more resistant to interference created by the solution to a previous task than people with low flexibility. Proponents of the interference explanation (e.g., Altmann & Gray, 2008) posit that, when a new task is presented following the completion of a prior task, the solution of the previous task interferes with the new solution. In a vigilance task, like the one in this study, participants may have attempted to anticipate the location of the next signal based on the knowledge of the previous signal's location. However, an alternative mechanism that might explain cognitively flexible behavior could be an individual's proclivity to notice environmentally-changing stimuli, i.e. a proclivity to notice bottom-up processes. Researchers who study how attention-capturing strategies can be optimized for signal salience have noticed differences in how signal color and luminosity affect rates of signal detection. Perhaps, then, cognitive flexibility is an increase in sensitivity to the changes in a visual field from one individual to the next.

Regardless of the mechanism(s) underlying cognitively flexible thinking, the theoretical and practical applications of this research extend to multiple types of vigilance tasks that have been identified in the field of Human Factors to be problematic. These applications include error-resistant medical devices, reliable airport security screening, accurate medical imaging, and effective loss prevention. Better understandings of how cognitive flexibility interacts with tasks that involve vigilance might lead to useful applications for designing optimal work schedules, equipment design, or both. Rather than employing one long task that includes many breaks throughout the day, employers might find that employees prefer shorter tasks that seem to be different, thereby allowing
them to exercise their natural tendency to switch tasks. Additionally, individuals with higher levels of cognitive flexibility may need to distract themselves from the primary task during breaks in order to return to prior levels of optimal signal detection.
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Training for vigilance: Using predictive power to evaluate feedback effectiveness.


*Perception and Psychophysics, 57*, 637-644.

Appendix A: Demographics Questionnaire

Gender: M _______  F _______

Age: _________________

Year in School: _______________

Major: _______________________

Ethnicity: (Circle one)
A. Caucasian
B. Black or African-American
C. Hispanic
D. Asian
E. Native Hawaiian or other Pacific Islander

F. Other _______________________

• How frequently do you solve puzzle for enjoyment (e.g., Sudoku, jigsaw puzzles, crossword puzzles)?

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<th>4</th>
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<td>Very frequently</td>
<td></td>
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Appendix B: Clock Task Timesheet

Participant #: 

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