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An Examination of Individual Differences in the Context of Performance on a Feedback v. No Feedback Vigilance Task

Jenny A. Walker
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AN EXAMINATION OF INDIVIDUAL DIFFERENCES IN WORKING MEMORY CAPACITY AND NEED FOR COGNITION IN TERMS OF PERFORMANCE ON A FEEDBACK VERSUS NO FEEDBACK VIGILANCE TASK

by

Jenny Autumn Walker

A thesis submitted in partial fulfillment of the requirements for the Honors in the Major Program in Psychology in the College of Sciences and in the Burnett Honors College at the University of Central Florida

Spring Term, 2016

Thesis Chair: Dr. Peter A. Hancock
ABSTRACT

When a task is boring, repetitive, and takes place over a long period of time, individuals have a propensity to experience a gradual decline in performance known as the vigilance decrement (Mackworth, 1948). This negative trend is consistent across most populations (Davies & Parasuraman, 1982), though slight variations can occur based on the characteristics of the task, as well as characteristics of the human performing it. However, despite the many differences between these tasks, most studies are similar in the sense that, more often than not, participants are provided with immediate feedback on their performance throughout most laboratory trials. Yet, in applied settings, feedback is not always feasible. In fact, in many circumstances, if real-time feedback such as this was always available, then the role of the human component of the system may be brought into question. This also may be concerning for validity of laboratory studies which utilize feedback. Therefore, one goal of this experiment, as well as future work, is to continue to assess the importance of feedback by examining differences in performance on a vigilance task during which feedback may or may not be present.

In addition to recent work relating to feedback, many current studies have also examined individual differences in the context of vigilance. Interestingly, it has been shown that performance accuracy often correlates to measures of higher order processing abilities including inhibition, which a component of working memory (Smallwood & Schooler, 2006). Additionally, when working memory load is increased, vigilant behavior also declines (Helton & Russell, 2011). Therefore, an additional goal of this study was to determine how performance relates to individual differences in higher order cognitive processing, such as working memory capacity and need for cognition. It was found that feedback does significantly improve
performance, which is worth considering as issues relating to vigilance decrements are addressed in applied environments. The individual differences measures did not yield any significant results.
DEDICATION

This piece is dedicated to my mother, father, and grandmother. I am forever grateful for your support. As in many aspects of life, this would not have been possible without you all. Gaby, thank you for helping me put out many fires along the way.
ACKNOWLEDGEMENTS

I would like to thank my supportive, inspiring committee: Dr. Peter A. Hancock, Dr. Valerie K. Sims, and Dr. Waldemar Karwowski. Dr. Hancock was incredibly positive, regardless of the challenges that arose throughout the process and provided a great deal of indispensable advice, humor, and reading recommendations. Dr. Sims has also provided nothing but positivity, and I would like to thank her for permitting me to present possible topics at laboratory meetings, assisting with the testing of my stimuli, and meeting with me to discuss details of the project on many occasions. I would also like to thank Dr. Waldemar Karwowski for allowing me to use his laboratory space and equipment, as well as accepting every change and challenge with a kind, understanding smile. Additional gratitude is in order for my mentors, Dr. Ben D. Sawyer and Gabriella M. Hancock, for their assistance with the experimental design, analysis, and write-up. I would also like to thank Brian Vermillion for his technical support and immense help with the building process. Keith MacArthur for remaining encouraging, and providing technical support.

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<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
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<tr>
<td>E</td>
<td>Effort</td>
</tr>
<tr>
<td>EEG</td>
<td>Electroencephalography</td>
</tr>
<tr>
<td>ERN</td>
<td>Error-Related Negativity</td>
</tr>
<tr>
<td>ERP</td>
<td>Event-Related Potential or Evoked-Responses Potential</td>
</tr>
<tr>
<td>ESU</td>
<td>External Sync Unit</td>
</tr>
<tr>
<td>F</td>
<td>Frustration</td>
</tr>
<tr>
<td>KR</td>
<td>Knowledge of Results</td>
</tr>
<tr>
<td>LCD</td>
<td>Liquid Crystal Display</td>
</tr>
<tr>
<td>NC</td>
<td>Need for Cognition</td>
</tr>
<tr>
<td>NCS</td>
<td>Need for Cognition Scale</td>
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<tr>
<td>MD</td>
<td>Mental Demand</td>
</tr>
<tr>
<td>MIT²</td>
<td>Minds in Technology/Machines in Thought</td>
</tr>
<tr>
<td>NASA TLX</td>
<td>National Space Administration’s Task Load Index</td>
</tr>
<tr>
<td>Ospan</td>
<td>Operation Span</td>
</tr>
<tr>
<td>P</td>
<td>Performance</td>
</tr>
<tr>
<td>PD</td>
<td>Physical Demand</td>
</tr>
<tr>
<td>SART</td>
<td>Sustained Attentional Response Test</td>
</tr>
<tr>
<td>TD</td>
<td>Temporal Demand</td>
</tr>
<tr>
<td>UCF</td>
<td>University of Central Florida</td>
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<td>WM</td>
<td>Working Memory</td>
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WMC  Working Memory Capacity
Introduction

In a time of rapidly-evolving, ever-expanding technological advancement and dependence, the success of many industrial, educational, and military endeavors is contingent upon the quality of human-machine interactions. However, the relationships between people and their technology are often far from perfect, and the results can be personally and professionally detrimental or even compromise public safety. One important, commonly-studied example of this type of shortcoming is known as the vigilance decrement. When tasks are mundane, repetitive, and lengthy, individuals have a propensity to experience a gradual decline in performance over time. This negative trend is generally consistent across most populations (Davies & Parasuraman, 1982), and, with few exceptions, almost everyone falls victim to vigilance decrements. Traditionally, it takes approximately 15-20 minutes for notable declines in performance to occur (Mackworth, 1948). There is also an extensive taxonomy of vigilance tasks which ranges from the classic, theoretically-grounded Mackworth Clock Task which is used solely in laboratory settings, to visual monitoring or cyber defense tasks which are more analogous to specific, applied situations (Warm & Dember, 1998).

However, despite their many differences, these tasks are united in the sense that, more often than not, participants are provided with immediate feedback on their performance throughout most laboratory trials. The decision to provide feedback is logical as doing so is easy, and possessing an accurate knowledge of results (KR) has proved to be helpful in mediating decrements (Szalma et al., 2006). KR is information about the outcome of a goal, and differs from knowledge of performance in the sense that no information is provided the individual about how the outcome was achieved (Salmoni, Schmidt, & Walter, 1984). For example, in an early
study conducted by Jane Mackworth (1964), participants were either provided with accurate KR, false KR, or no KR throughout a Mackworth Clock Task in the form of immediate feedback upon the commitment of a mistake. The best performances were associated with an accurate KR. False KR yielded moderately successful performance, and participants who received no KR, by far, performed the worst and declined at a similar rate to the false KR group. In addition to mitigating the performance decrement, providing feedback also improves overall reaction time (Church & Camp, 1965).

Yet, despite these benefits to effectiveness and efficiency, feedback is not always provided in applied settings. In fact, in many circumstances, if real-time feedback such as this was available, then the human component of the system would not be necessary in the first place. This may bring the validity of applied studies which utilize feedback into question. Consequently, one goal of this experiment, as well as future work, is to continue to assess the importance of feedback by examining differences in performance on a vigilance task when feedback is and is not present.

In addition to recent work relating to feedback empirical research has also examined individual differences in the context of vigilance. The impetus driving this particular line of research is the need for a thorough understanding of the cognitive scaffolding which underlies slight but highly important variations in human performance on vigilance tasks (Matthews, Davies, Westerman, & Stammers 2000; Grier et al., 2003). Working memory capacity (WMC) is one such individual differences measure, and is of particular interest for this study due to its possible relationship with the cognitive processing associated with feedback. Working memory (WM) is the transitory processing, parsing, storage, and retrieval that individuals depend upon in
order to complete cognitive tasks (Baddeley, 1982). Unlike long-term or sensory memory, which are vast and do not have established, theoretical limits, working memory has a capacity which dictates the amount of information that a given individual is able to simultaneously process (Cowan, 2008).

To clarify, WMC is not a measure of intelligence (Unsworth & Engle, 2005). Rather, it is a value which represents the availability of higher order resources; and individuals with high WMCs are therefore able to accomplish more cognitive processing with the same amount of effort as their lower WMC counterparts. Ultimately, WMC represents an indicator of proactive control abilities (Richmond, Redick, & Braver, 2015), and is best measured with span tasks which utilize simultaneous processing paradigms (Conway et al., 2005).

Specifically, WM is a worthwhile construct to examine in the context of vigilance because, though vigilance tasks themselves are simple in design, their continuously-changing nature and characteristics (such as the presence of feedback) affords additional cognitive complexity which may compromise the performance of those individuals with low WMCs. This relationship is implied by the direct cost model of vigilance, which has gained an exponential amount of support in modern literature (Hancock & Warm, 1989; Warm, Parasuraman, & Matthews, 2008; Szalma, 2001). The direct cost model states that decrements are the result of a depletion of mental resources over time. Though the act of waiting for a critical signal during a vigilance task is visually passive, it is mentally active as many components of higher order processing are at play. Continuously taking in new information (such as performance feedback) while simultaneously disregarding old information, avoiding false alarms, and ignoring distractions requires a great deal of cognitive resources (Grier et al, 2003).
Additionally, the direct cost model is supported by a massive collection of studies which examine the nature of vigilance tasks themselves, self-report scales, individual differences, and physiological measures. For example, the Sustained Attentional Response Test (SART) measures one’s ability to inhibit improper responses relative to the population (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). Inhibition is a component of working memory, and also plays a role in preventing false alarms (Jonides, Smith, Marshuetz, Koepppe, & Reuter-Lorenz, 1998). In a study conducted by Smallwood & Schooler (2006), it was shown that SART scores have a highly significant, positive correlation with individuals’ performance on vigilance tasks. In another study conducted by Helton and Russell (2011), it was shown that increasing verbal working memory load will negatively impact vigilant behavior as there appears to be a direct cost trade-off taking place between processing and decision making.

Another individual differences measure of interest is need for cognition (NC). NC is defined as a natural inclination towards activities which are mentally stimulating and require effortful cognitive processing. Such pursuits may include, but are not limited to, completing critical thinking puzzles, learning to read music, writing books, etc. (Cohen, Stotland, & Wolfe, 1955). Having a low NCS score is not directly indicative of seeking out under-stimulating activities. Rather, this classification represents happiness at levels of cognitive stimulation which are no different than normal. Those who have a high NCS score are the individuals who go beyond what is necessary to function in everyday life. On the other hand, those who have a low NC tend not to seek as much cognitive stimulation, have a propensity towards procrastination, and often engage in social loafing (Schuller, 1999; Haugtvedt, Petty, & Cacioppo, 1992). There appears to be little to no research conducted about how one’s NC relates to sustained attention or
performance on vigilance tasks. Rather, this factor tends to be more often studied using brief, visually variable stimuli, such as videos of crimes for eyewitness testimony (Leippe, Eisenstadt, Rauch, & Seib, 2004) or advertisements designed to elicit consumer behavior (Haugtvedt, Petty, & Cacioppo, 1992). Though vigilance tasks themselves are not necessarily enjoyable, different individuals may approach them in different ways (i.e. an opportunity to challenge oneself versus an irritating chore), and that perspective may impact performance.

Hypotheses

As a whole, working memory is a clear contributor to vigilance behavior and may provide interesting results in terms of performance feedback. It is hypothesized that, in the feedback condition, individuals with a larger WMC will commit fewer errors over time as they are able to process additional simultaneous information, and thereby extrapolate more from the provided KR. In the no feedback condition, the decrement will be more severe overall, but there will be little to no difference between the low and high WMC groups. In terms of NC, there will be no difference between low and high individuals in the no feedback condition. However, for the feedback condition, individuals with a higher NC will experience a less severe decrement because they are more likely to devise pleasure from the task or view it as an opportunity to challenge oneself.
Method

Power Analysis

An *a priori* power analysis was conducted using G*Power* (Faul, Erdfelder, Buchner, & Lang, 2009; Faul, Erdfelder, Lang, & Buchner, 2007). The effect size (f=.4) used for this procedure was obtained from values from similar effect sizes observed in previous empirical findings (Parasuraman & Davis, 1976). In order to achieve 95% power, this experiment requires a sample size of 24 participants.

Participants

41 undergraduate students from UCF participated in this study. They were recruited via the UCF SONA research participation system, as well as fliers posted around the campus. Individuals received 2 credits (one for each hour) in exchange for their time if they were enrolled in a course which requires active research involvement. Otherwise, participation in this study was completely voluntary. Demographic questions were used in order to identify individuals who had ingested caffeine immediately prior to the study, had been previously diagnosed with a neurological disorder, or were under the influence of a physiological stimulant (Adderall, cocaine, etc.) via self-report. No participants needed to be removed from any analysis per this criterion.

A total of eleven participants were excluded in the final analyses. One fell asleep during the protocol, and another was chewing gum (Morgan, Johnson, & Miles, 2014). One participant became incredibly angry during the task, talked to herself for a short period of time, kicked the
table, and turned around to stare at the researcher for several minutes. Two participants were visibly not putting forth any effort, stopped responding to the stimuli mid-trial, and looked around the room on multiple occasions. Two participants indicated that they did not understand what was expected of them after the vigil and did not manage to indicate any correct detections—one stating “I just didn’t get it,” and the other insisting that there was some sort of trickery built into the feedback when this was not the case. The remaining four individuals were wearing electroencephalography (EEG) equipment and had longer set-up times than other participants, and their inclusion may have presented possible confounds. Due to technical issues and time constraints, the use of EEG for this study was not possible (see Appendix A).

Participants were free to end their participation at any time, though none did. This study was approved by the UCF Institutional Review Board prior to recruitment and collection (see Appendix F).

Materials

This study took place in room with no external windows that is located behind several locked doors, minimizing extraneous noise to the greatest possible extent. Furthermore, there were no clocks or any indicators of time displayed anywhere during the vigilance portion of the experiment. There is a small fan available should the room become too warm, though this was not an issue. The participant’s chair is heavy and does not swivel because that may present a distraction. There is darkened glass around the door to the experimental space, and the researcher sat at a table approximately three feet behind the participant throughout the vigil. The experimenter did not use any electronic devices which could have introduced noise, and instead
entered information into run sheets, updated SONA credit, and viewed scripts using silent touch
screen devices.

The vigilance task is a go-no-go variation of a Mackworth Clock. It consists of a large
circle which has a diameter of 480 pixels, and is comprised of sixty outlines of circles which
each have a diameter of 9 pixels. A white dot moves from one small circle to the next at a rate of
50 jumps per minute—or one jump every 1.2 seconds. This event rate is slightly lower than that
of a traditional Mackworth Clock Task (60 jumps per minute). This is because the task was
titrated in order to induce a decrement in performance. An event rate of 60 jumps per minute
caused a severe floor effect, while 40 or 45 jumps per minute caused severe ceiling effects.
Therefore, it was determined that 50 jumps per minute was the best event rate. Critical signals
occur when the dot jumps double the distance of a non-critical signal, and the probability of
occurrence was 5%. Participants are responsible for pressing “Skip” and “No Skip” buttons on a
keyboard to indicate whether a single or double jump occurred each time. All other buttons were
removed in order to prevent participants from becoming distracted or accidently aborting the
trial. Requiring that participants respond to both events and non-events differs from the original
Mackworth Clock Task, for which participants only responded to events. However, this
modification enables the identification of different types of errors (false alarms, non-presses, and
misses), and this information is important for later applications in physiological studies. This
task was built as a custom Java program, and collects information about reaction time, the type
of event (jump vs. double jump), and the type of response (skip vs. no skip). The feedback
consisted of a red X for every miss, false alarm, or no key press. The stimuli was presented in the
center of a 20-inch LCD monitor (E-Series, Dell, Plano, TX, USA), and the participants were permitted to move the keyboard forward or back for their comfort.

The Operation Span (Ospan) was used to measure participants’ WMC, a widely used measure which has been empirically shown to be reliable (Unsworth, Heitz, Schrock, & Engle, 2005). It begins with a brief training which teaches individuals how to respond to math questions and indicate the order of letters. The task itself consists of letters which briefly appear on screen. After each letter, a math problem is shown and participants are asked to solve the problem in their head. A possible answer to the math problem is then presented and they must indicate if it is true or false. After completing this cycle several times, participants are asked to recall which letters were presented in order. The number of letters and accompanying math problems that that participant is asked to recall and solve varies throughout the trial. The Ospan is presented on a laptop with Eprime ERun version 2.0.10 (Psychology Software Tools Inc, Pittsburg, PA, USA).

Aside from the vigilance task and Ospan portions of this experiment, all other measures are administered via Qualtrics (Qualtrics Inc., Provo, UT, USA). The National Aeronautics and Space Administration Task Load Index (NASA TLX) is an inventory which measures the immediate mental demand, physical demand, temporal demand, effort, perceived performance, and frustration associated with a task—in this case, the Mackworth Clock Task—on a very low-very high, 21-level Likert scale (Hart & Staveland, 1988). The NASA TLX is used to determine individuals’ cognitive load subsequent to the experimental trial. NC was measured using the Need for Cognition Scale (NCS). This is a short inventory which asks participants to rate their agreement with 18 statements about how much mental stimulation they experience, seek, and enjoy on a nine-level Likert scale (Cacioppo & Petty, 1982).
Design

This study utilizes 2 X 2 between-subjects experimental designs: feedback (present and absent), and WMC and NC individual differences measures (low and high). The primary dependent variable of interest is over response accuracy, measured as a percent of correct detections, throughout the vigilance task. Examinations of the NASA TLX are exploratory. Accuracy during the training portion of the experiment serves as a control.

Procedure

Upon arrival, participants were asked to silence their cell phones, remove their watches, put away any food or drinks, and spit out any gum they were chewing. Individuals were also advised that, if they needed to get a drink of water or use the restroom, it was best to do so prior to the experiment. Sounds, clocks, chewing, and feelings of discomfort are types of external and internal distractions which could impact results. They then read an informed consent form, the general experimental procedure was explained to them, and any questions about participant rights and responsibilities were answered. They did not need to sign the informed consent, but copies were made available in case they wanted one for their records.

Once the consent process was complete, the Mackworth Clock task was explained and they completed two 2.5-minute training sessions. For the training, the signal probability was set at 10% in order to ensure that participants viewed and responded to a sufficient number of critical events (i.e. double jumps). The event rate of the actual trial is too low for a brief session. Once one training session contained feedback, and the other did not. The order was counterbalanced across subjects. The participants were then asked to reconfirm that they
understood what task entailed. If they reported that they did not understand, then it was possible for the training to be repeated. Only two subjects repeated the training, but they were not included in the final analyses for other reasons. Only once individuals indicated that they fully understood how to respond to jumps and double jumps, did the task itself begin. Individuals completed a 40-minute trial of the Mackworth Clock Task. One condition contained immediate performance feedback, and the other did not contain any additional information relating to performance.

At the end of the 40 minute trial, the participants immediately completed the NASA TLX. Then they were required to take a break during which they were encouraged to stretch, take a short walk, look at their phones, use the restroom, or get a drink of water. Resting was not optional. This step is highly important as the carry-over effects from the vigilance task needed to be minimized while filling out inventories. The NASA TLX is an exception as it is intended to measure cognitive load in direct response to the task. When the participants were ready to return to the experiment, they completed the Ospan first, then a demographics questionnaire, then the NCS. The entire experiment took each participant approximately 1 hour and 45 minutes.
Results

Vigilance

Correct detection data were collected and analyzed for a total of 30 participants (18, males, 12 females). 15 were in the feedback condition, and 15 were in the no feedback condition. Participants ranged in age from 18-28 years \((M = 19.24, SD = 1.91)\). The means and standard deviations of correct detection data were obtained from the training sessions, and thereby used to eliminate 2 outliers. Both of the participants excluded via this criterion did not indicate a single correct detection, despite completing the training twice, and performed extremely poorly on the vigilance task itself. Their results indicate that they either did not understand the task, did not put forth significant effort, or experienced some sort of cognitive or physical struggle that impeded effective performance. For the participants included in the final analyses, the mean percent of correct detections over time and the accompanying standard error values are included in Table 1.

Table 1: Percentage Correct Detections and Standard Error Values

<table>
<thead>
<tr>
<th>Time (in minutes)</th>
<th>Feedback</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>No Feedback</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Correct Detection</td>
<td>0.73</td>
<td>0.66</td>
<td>0.6</td>
<td>0.66</td>
<td>0.68</td>
<td>0.56</td>
<td>0.54</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Standard Error (SE)</td>
<td>0.061</td>
<td>0.058</td>
<td>0.059</td>
<td>0.047</td>
<td>0.061</td>
<td>0.058</td>
<td>0.058</td>
<td>0.047</td>
<td></td>
</tr>
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</table>

As shown in Figure 1, for both conditions, the first 10-minute period of watch was associated with the highest performance values. These starting values are slightly lower than the expected, but are still comparatively high. The following periods of watch were characterized by gradual declines in performance. This general trend coincided with my expectations, as it corresponds with the traditional vigilance decrements (Mackworth, 1948).
One exception to this trend, however, is seen in the final period of watch for the feedback group which experienced an increase in correct detections when compared to the no feedback group. This sudden upturn in performance for the feedback group aligns with previous research (Wiener & Attwood, 1968). The vigilance data were analyzed using a 2 (feedback and no feedback) X 4 (10, 20, 30, and 40 minutes) mixed analysis of variance (ANOVA). Though the main effect was small, the feedback group exhibited significant, superior performance when compared to the no feedback group, \( F(1,112) = 4.098, p = .045, \eta^2 = .035 \). Pairwise comparisons show that the feedback group performed better on the vigilance task overall (mean difference = .086, \( p = .045 \)). According to the omnibus univariate ANOVA, there was no significant main effect for time \( F(1,112) = 2.124, p = .101 \).

![Performance During Vigil](image)

**Figure 1: Performance on the Vigilance Task**
The false alarm rate was less than 1% in both conditions which is extremely low. Additionally, nearly all false alarms were immediately prior to misses. Therefore, they were not analyzed further.

**Working Memory Capacity**

The participants did not present a uniform distribution of WMC scores. Therefore, it is not possible to properly divide them into low and high WMC groups for analysis. Ospan values range from 0 to 75, with 0 representing the lowest possible WMC score and 75 representing the highest WMC score. Traditionally, low and high WMC individuals are identified as those contained within the 1st and 4th quartiles. However, all but 2 participants fell within the upper 3rd and 4th quartiles. Therefore, the distribution of these subjects was drastically shifted to the right in both the feedback ($M = 59.4$, $SD = 11.13$) and no feedback conditions ($M = 55.4$, $SD = 14.77$). In fact, the feedback condition contained no ‘low’ WMC scores at all, and 2 of the 15 participants received maximum scores.

Additionally, in order to determine if individual subjects’ results are reliable, the scores on the mathematics portion of the Ospan are examined. The mathematics problems which are used in the Ospan are not particularly challenging as they consist of single digit operations (i.e., $7 - 4$). The instructions also clearly state that maintaining one’s math percentage score at a high point is important, and after each set round of problems and recall participants are provided with their current score. Therefore, if individuals do not score at or above 85%, this may be an indicator that they did not understand the task properly, have a cognitive disability, did not put effort into their participation, or another issue occurred which was beyond having a low WMC.
Usually, a few subjects are removed due to this factor. However, no subjects in this sample scored below 90% on the mathematics portion, and that is highly unusual. Overall, this sample had a disproportionately large number of ‘high’ WMC individuals relative to the general population and cannot be analyzed as intended.

**Need for Cognition**

First, a mixed ANOVA was conducted on the NC scores as a dichotomy of low and high, with the dependent variable being percentage of correct detections during the entire vigil. The results were not significant $F(1,28) = 0.649, p = .423$. However, due to the small sample size, as well as the uneven split between low and high NC participants (7 in the low NC group and 23 in the high NC group), a simple linear regression was also performed using the NC scores as a continuous predictor variable. The results were likewise not significant $F(1,28) = .390, p = .537$, $R^2 = .014$, which suggests that NC does not appear to be a predictor of performance on this vigilance task.

**NASA TLX**

A multivariate ANOVA was conducted on the 6 subscales of the NASA TLX: mental demand (MD), physical demand (PD), temporal demand (TD), performance (P), effort (E), and frustration (F). The results indicate that there was not a significant effect between the feedback and no feedback conditions $F(6,27) = .468, p = .824$. However, according to the pairwise comparisons, perceived temporal demand is approaching significance (mean difference = 2.67, $p$
= .08), with those in the no feedback condition reporting greater perceived temporal demand than those participants in the feedback condition.

Table 2: Means of NASA TLX Subscales

<table>
<thead>
<tr>
<th></th>
<th>Feedback</th>
<th></th>
<th></th>
<th>No Feedback</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MD</td>
<td>PD</td>
<td>TD</td>
<td>P</td>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>Mean</td>
<td>50</td>
<td>25</td>
<td>29.6</td>
<td>60.7</td>
<td>51.8</td>
<td>56.4</td>
</tr>
<tr>
<td>Standard Error (SE)</td>
<td>7.73</td>
<td>7.77</td>
<td>4.85</td>
<td>7.2</td>
<td>7.2</td>
<td>7.42</td>
</tr>
</tbody>
</table>

Table 3: Pairwise Comparisons of NASA TLX Subscales

<table>
<thead>
<tr>
<th></th>
<th>MD</th>
<th>PD</th>
<th>TD</th>
<th>P</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Difference</td>
<td>10</td>
<td>2.67</td>
<td>13.4</td>
<td>7.04</td>
<td>3.55</td>
<td>0.9</td>
</tr>
<tr>
<td>F</td>
<td>0.93</td>
<td>0.07</td>
<td>2.41</td>
<td>0.63</td>
<td>0.11</td>
<td>0.01</td>
</tr>
<tr>
<td>Sig</td>
<td>0.34</td>
<td>0.8</td>
<td>0.13</td>
<td>0.44</td>
<td>0.75</td>
<td>0.93</td>
</tr>
<tr>
<td>Partial η²</td>
<td>0.03</td>
<td>0.02</td>
<td>0.08</td>
<td>0.02</td>
<td>0.04</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Discussion

A significant main effect was found between the feedback and no feedback conditions in terms of performance. As predicted, the feedback group experienced a less severe decrement, and the percent of correct detections they indicated remained higher than that of the no feedback group throughout the length of the vigilance task. There was also a slight upturn in performance at the end of the 40-minute trial in the feedback condition, which aligns with previous findings from empirical vigilance research (Wiener & Attwood, 1968; Bergum & Lehr, 1963). These findings contribute additional support to the benefits of KR, and show that providing individuals with more information about their performance can be helpful in mediating a serious issue in human-machine interaction. At the same time, these findings are also troubling as immediate feedback is usually not present in the majority of applied scenarios. When safety, security, and lives are at stake, even small declines in performance should not be taken lightly. These findings are also worth considering during the development of studies which are intended to be analogous to real-life situations.

The participants’ WMC scores were not analyzed for this study as low WMC individuals were not properly represented in the sample. When a collegiate population is used for a WMC study, it is common for results to be slightly skewed to the right. However, this sample was comprised almost solely of unusually high WMC scores, and the feedback condition did not contain a single low WMC individual. It appears that most of the cognitive fatigue associated with completing the vigilance task was eliminated by taking a break. However, the Ospan scores obtained in this study could not be analyzed. This non-uniform distribution may be due to the fact that the majority of the participants were students majoring in engineering or computer
science which is a field that necessitates effective simultaneous processing abilities, as well as the small sample size relative to most studies pertaining to individual differences in WMC. In order to eliminate this issue in future studies, participants should be pre-screened based on their Ospan scores, and only return to complete the vigilance task if they have been identified as having an empirically determined low (in the 1st quartile) or high (in the 4th quartile) WMC. If, upon the elimination of this issue, the hypotheses that individuals with a high WMC were to perform better in the feedback condition than the low WMC individuals were supported, then the findings would provide additional support to the direct cost model of vigilance and show that those who are able to process more simultaneous information are the ones who truly benefit from KR.

The NCS results were also skewed in the negative direction, with only 7 out of the 30 participants identified as having a low NC. This is most likely due to the fact that the sample is comprised of college students who are paying for and actively seeking educational enrichment beyond what is mandated by law. When compared to the overall performance on the vigilance task, no significant interactions were identified. It is possible that NC is not a predictor of one’s ability to maintain attention during a vigilance task. However, due to the sample size and underrepresentation of low NC individuals, it is difficult to confirm.

There were also no significant results pertaining to the NASA TLX between conditions. Neither the feedback nor the no feedback groups indicated that they were experiencing significantly higher mental workload than the other. Temporal demand was approaching significance, with individuals in the no feedback condition reporting slightly higher levels of
mental workload. Though not significant, this finding is logical as having to monitor one’s performance without the aid of feedback may be mentally taxing.

**Future Research**

The Mackworth Clock Task is common in laboratory settings. However, it is not visually analogous to most real-life vigilance scenarios. It was chosen for this study because it is conceptually simplistic, easy for participants to understand, and presents a good foundation for future work. However, in regard to drawing conclusions about specific, applied vigilance scenarios such as long-distance driving, security, and cyber defense, that is best accomplished with tasks which are more representative of those environments. Therefore, later studies will utilize a variety of vigilance tasks in order to determine if the conclusions drawn from this study are truly replicable and generalizable.

Additionally, incorporating psychophysiological measures, such as EEG would provide a new perspective on vigilance performance which goes beyond response accuracy alone. Understanding the neurological foundation of sustained attention is important because that perspective better addresses the issue of performance decrements on an individual level. On a similar note, it would also be worthwhile to examine additional individual difference measures which include, but are not limited to, propensity towards mind wandering, baseline stress levels, and proneness to boredom.

**Limitations of Present Research**
This study had several limitations including time, funding, and the availability of representative student populations. Additionally, the timeslots associated with this study were relatively long, and receptiveness of the subject pool was inconsistent.

Conclusions

Providing feedback to individuals improves their overall performance on a vigilance task. Though the decrement itself is not entirely eliminated in the presence of feedback, humans are better able to modify their performance using their KR because. The WMC and NC individual differences measures did not yield any significant results. However, in future research, this type of analysis may greatly benefit from having larger sample sizes, as well as a more even split between low and high scores on the traits of interest. These findings further emphasize the benefit of providing feedback to individuals when the tasks they are completing are long, repetitive, and boring. However, due to the fact that immediate feedback is usually not available in applied environments, findings such as this should be taken into consideration when addressing issues relating to human-machine interaction and sustained attention.

Vigilance research is crucial because many mundane, cognitively demanding tasks directly put personal welfare and public safety at risk. This is because vigilance tasks place disproportionally challenging—and, in many cases, impossible—performance expectations on individuals. The resulting iatrogenic state is a fate that few are immune from (Hancock, 2013), and is characterized by a flurry of stress, anxiety, and cognitive depletion which only exacerbates the issue. The human factor should never be ignored or replaced entirely (Warm, Dember, Hancock, 1996). Ultimately, developing a more complete understanding of task characteristics
(such as the presence or of lack feedback), as well as the role of individual differences in
cognition, facilitates the development of solutions and pushes the plight of individuals and others
who are impacted by these failures in human-machine interaction to the forefront.
Appendix A: Electroencephalography Measures
Summary of Additional Introduction

Error-related negativity (ERN) is a type of event-related potential (ERP) that occurs when an individual perceives that he or she has committed an error. (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990; Gehring, Coles, Meyer, & Donchin, 1990). The ERN primarily occurs at the Cz Brodmann’s region of the scalp, which lies above the anterior cingulate cortex, as well as its neighboring regions (Luck & Kappenman, 2011). The ERN is occasionally used as a measure of interest in attention studies, though it is not common in the context of vigilance research. Therefore, this underexplored measure may provide insight into some of the physiological responses that underlie sustained attention. Specifically, this portion of the study attempted to examine individual differences in the amplitude and latency of the ERN waveforms over time, as well as use the ERN as a tool to determine if people depend on feedback in order to identify mistakes.

Additional Method

ERN electroencephalographic data was collected using the B-Alert X-10 wireless EEG system and the accompanying B-Alert Live software. This is a 9-lead, wet set up which uses a water-soluble electro-conductive gel for signal amplification. The wireless headset rests over the occipital region of participants’ scalp and is secured with a head strap. The nine leads of this headset correspond to the F3, Fz, F4, C3, Cz, C4, P3, POz, and P4 Brodmann’s regions. The size of the strip is determined by measuring the participants’ head with a tape measure, and reference leads are placed over the mastoid processes. The head strap, strips, tape measure, and headset are all cleaned and sanitized with isopropyl alcohol between trails. An External Sync Unit (ESU)
establishes a wireless connection between the EEG headset and software. The goal was to have
timestamped events (keypresses) sent via a serial port to the ESU, which would then be
incorporated into the data within the B-Alert Live software. For each participant, two types of
data were produced: the Mackworth Clock Tasks data collected by the Java program (which
contained information about the type of event, response, and reaction time), and the EEG data
collected by the B-Alert software with timestamps which could later be binned and interpreted in
MATLAB.

Issues & Rectification Attempts

There were two serious issues: the timestamps in the Mackworth Clock Task data output
did not match those in the EEG data, and the number of responses in the Mackworth Clock Task
data output did not match that which represented in the EEG data. For example, one participant’s
Mackworth data indicated that the trial took exactly 40 minutes and there were 1956 keypresses.
Yet, the EEG data indicated that the trial took 47 minutes and 1516 key presses occurred.
Therefore, the packets of information sent via the serial port to the ESU were both delayed and
incomplete. Three strategies were used in an attempt to mediate the issue.

1. Going through the EEG data spreadsheets by-hand.

At first glance, it seemed possible that there was something wrong with the format
in which the EEG data output which was being extracted from the B-Alert software.
It may have been possible that all of the correct information was there, but just
labeled incorrectly or hidden. Upon an extensive, line-by-line search through all of
the files output by the B-Alert software, it became clear that the correct data was not there.

2. Manually addition of timestamps

   An attempt was made to build an equation in Microsoft Excel which would manually add timestamps to the EEG data in all of the correct places and adjust for the time delays. However, this was also a futile effort due to the fact that was impossible to accurately determine the starting point in the EEG data. ERPs are highly sensitive to time as they are measured in milliseconds. Even small delays can have serious consequences. The ERP waveforms which were graphed after using this technique were nonexistent.

3. Contacting technical support systems outside of the laboratory.

   Attempts were made to address this issue with the assistance of several, experienced programmers both on the UCF campus and from B-Alert. Despite a great deal of work on the part of many incredibly helpful and dedicated people, no significant progress was made.

   Due to the strict timeline establish by the UCF Honors in the Major Program, as well as resource constraints, it was determined that this portion of the experiment would be reserved for a later date.
Appendix B: Mackworth Clock Stimuli
Appendix C: Need for Cognition Scale
Please rate the extent to which you agree with each of these statements.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Very Strongly Disagree</th>
<th>Strongly Disagree</th>
<th>Moderately Disagree</th>
<th>Slightly Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Slightly Agree</th>
<th>Moderately Agree</th>
<th>Strongly Agree</th>
<th>Very Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I would prefer complex to simple problems.</td>
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<tr>
<td>I like to have the responsibility of handling a situation that requires a lot of thinking.</td>
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<tr>
<td>Thinking is not my idea of fun.</td>
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<tr>
<td>I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.</td>
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<tr>
<td>I try to anticipate and avoid situations where there is likely a chance I will have to think in depth about something.</td>
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<tr>
<td>I find satisfaction in deliberating hard and for long hours.</td>
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<tr>
<td>I only think as hard as I have to.</td>
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<tr>
<td>I prefer to think about small, daily projects to long-term ones.</td>
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</tr>
<tr>
<td>I like tasks that require little thought once I've learned them.</td>
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<tr>
<td>The idea of relying on thought to make my way to the top appeals to me.</td>
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<td></td>
</tr>
<tr>
<td>I really enjoy a task that involves coming up with new solutions to problems.</td>
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</tr>
<tr>
<td>Learning new ways to think doesn't excite me very much.</td>
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</tr>
<tr>
<td>I prefer my life to be filled with puzzles that I must solve.</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>The notion of thinking abstractly is appealing to me.</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>I feel relief rather than satisfaction after completing a task that required a lot of mental effort.</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It's enough for me that something gets the job done; I don't care how or why it works.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I usually end up deliberating about issues even when they do not affect me personally.</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix D: NASA Task Load Index
Default Question Block

**Self:**

How mentally demanding was the task?

<table>
<thead>
<tr>
<th>Very Low</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21</td>
<td></td>
</tr>
<tr>
<td>Mental Demand</td>
<td></td>
</tr>
</tbody>
</table>

How physically demanding was the task?

<table>
<thead>
<tr>
<th>Very Low</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21</td>
<td></td>
</tr>
<tr>
<td>Physical Demand</td>
<td></td>
</tr>
</tbody>
</table>

How hurried or rushed was the pace of the task?

<table>
<thead>
<tr>
<th>Very Low</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21</td>
<td></td>
</tr>
<tr>
<td>Temporal Demand</td>
<td></td>
</tr>
</tbody>
</table>

How successful were you in accomplishing what you were asked to do?

<table>
<thead>
<tr>
<th>Very Low</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21</td>
<td></td>
</tr>
<tr>
<td>Performance</td>
<td></td>
</tr>
</tbody>
</table>
How hard did you have to work to accomplish your level of performance?

<table>
<thead>
<tr>
<th>Effort</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
</tr>
</thead>
</table>

How insecure, discouraged, irritated, stressed, and annoyed were you?

<table>
<thead>
<tr>
<th>Frustration</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
</tr>
</thead>
</table>
Default Question Block

Participant # (to be filled out by the research assistant):

What is your age?

What is your gender?

Male

Female

Other

What is your major?


Right or left handed?

‘Forced Handedness’ means you use one hand because you are unable to use the other.

Right
Left
Ambidextrous
Forced Handedness

Have you ever been diagnosed with any neurological disorder(s)?

Yes
No

If you have been diagnosed with any neurological disorder(s), please explain briefly.

[Blank]

What is your first language?

English
Spanish
Other

List all of the languages you can speak fluently.

[Blank]
Are you currently wearing corrective lenses?
Yes, glasses
Yes, contacts
No

Have you ingested any caffeinated beverages (coffee, tea, caffeinated soda, etc.), pills, powders, or energy shots prior to participating in this study?
Yes
No

Have you ingested any Adderall® or other amphetamines prior to participating in this study?
Yes
No

Had you ever seen the clock stimuli before today?
Yes
No

Powered by Qualtrics
Appendix F: IRB Approval Letter
Approval of Human Research

From: UCF Institutional Review Board #1
FWA00000351, IRB00001138

To: Benjamin Sawyer

Date: July 20, 2015

Dear Researcher:

On 07/20/2015, the IRB approved the following minor modification human participant research until 02/23/2016 inclusive:

- **Type of Review**: IRB Addendum and Modification Request Form
- **Modification Type**: In addition to recruiting study participants via Sona, participants will also be recruited via a flyer. The recruitment flyer has been uploaded to IRIS, along with a revised protocol. A revised Informed Consent has been approved for use.
- **Project Title**: Electrophysiological Measures of Human Error
- **Investigator**: Benjamin Sawyer, MS Industrial Engineering
- **IRB Number**: SEE-14-10161
- **Funding Agency**: N/A
- **Grant Title**: N/A
- **Research ID**: N/A

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30 days prior to the expiration date for studies that were previously approved, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form cannot be used to extend the approval period of a study. All forms may be completed and submitted online at https://irisresearch.ucf.edu.

If continuing review approval is not granted before the expiration date of 02/23/2016, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in IRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Page 1 of 2
Appendix G: Participant Recruitment Flier
Would you like to participate in an EEG study?

“An Electrophysiological Measurement of Cognition”
Sign up via the UCF SONA system for class credit
or
Contact the Principal Investigator Ben D. Sawyer from the MIT² Laboratory
mit2ras@gmail.com

The purpose of this study is to examine physiological measures during a cognitive task.
Location: ENGI room 315
Duration: 2 hours

Participants must be 18 years of age or older in order to participate, not wear glasses or contacts, be right-handed, speak English as their first language, and must be in compliance with IRB protocol in order to participate in this study.
Appendix H: Informed Consent
Title: Electrophysiological Measures of Human Error

Informed Consent

Principal Investigator: Ben Sawyer

Co-Investigator: Jenny Walker
Daniellys Diaz
Rebecca McKeogh
Chibundo Egwuatu
Keith MacArthur

Faculty Advisor: Dr. Peter Hancock Ph.D.

Sites of Investigation: UCF Engineering 2 Building or UCF Psychology Building

Introduction: Researchers at the University of Central Florida (UCF) study many topics. To do this we need the help of people who agree to take part in research studies. You are being invited to take part in a research study which will include about 200 people at UCF. You have been asked to take part in this research study because you are a student at the University of Central Florida. You must be 18 years of age or older to participate in this study.

This study is being conducted in the state of Florida. The person doing this research is Ben Sawyer from the University of Central Florida. Because Ben Sawyer is a graduate student, he is being guided by Peter Hancock, a UCF faculty supervisor in the Psychology Department. UCF Students learning about research are helping to do this study as a part of a research team. Their names are Jenny Walker, Daniellys Diaz, Rebecca McKeogh, Chibundo Egwuatu, and Keith MacArthur.

What you should know about this research study:
• Someone will explain this research study to you.
• A research study is something you volunteer for.
• Whether or not you take part is up to you.
• You should take part in this study only because you want to.
• You can choose not to take part in the research study.
• You can agree to take part now and later change your mind.
• Whatever you decide it will not be held against you.
• Feel free to ask all the questions you want before you decide.
Purpose of the research study: The purpose of this study is to examine physiological measures during a cognitive task.

What you will be asked to do in the study: You will be fitted for a noninvasive electroencephalogram (EEG) head strap and electrodes by a research assistant. You may also be fitted with physiological measuring equipment requiring sensors secured to your finger(s) with Velcro straps. You may also be calibrated to an eye tracker. Your session may be audio recorded; if so, please do not verbalize any identifiable information during the study. You will then complete a series of cognitive tests on a computer, fill out a series of surveys, and complete the study with a demographics questionnaire.

Location: This study will take place on the UCF campus in the Psychology Building, rooms 113 and 303D, or Engineering II, rooms 315 and 315B

Time required: We expect that you will be in this research study for 2 hours

Audio or Video Taping: This study may be audio recorded. If you do not wish to be audio taped, you will still be able to participate in this study. Discuss this with the researcher or a research team member. If you are audio taped, the tape will be kept in a locked, safe place. The tape will be erased or destroyed once the necessary information has been obtained from it.

Risks: This study may be audio recorded. If you do not wish to be audio taped, you will still be able to participate in this study. Discuss this with the researcher or a research team member. If you are audio taped, the tape will be kept in a locked, safe place. The tape will be erased or destroyed once the necessary information has been obtained from it.

Benefits: There are no expected benefits for taking part in this study. We cannot promise any benefits to you or other from your participation in this research.

Compensation or payment: There is no monetary payment offered for this study; however, SONA credits are available to those who signed up through the online SONA system. Once you complete your participation in the study, verification will be recorded in the SONA system. There is no direct compensation for taking part in this study. It is possible, however, that extra credit may be offered for your participation, but this benefit is at the discretion of your instructor. If you choose not to participate, you may notify your instructor and ask for an alternative assignment of equal effort for equal credit. There will be no penalty. If you did not sign up for this study through the SONA system, participation is entirely voluntary.

Confidential research: Your name, birthdate and any other identifiable characteristics will not be viewed by any person outside of the SONA system. Your identity will be kept completely confidential. Your information will be assigned a number that cannot be traced back to your person. All of the information from the study will be kept in a locked filing cabinet or stored on a password protected computer. When the researchers write about this study, they will not have any access to or use any of your personal, identifiable information.
Study contact for questions about the study or to report a problem: If you have questions, concerns, or complaints please contact the MIT2 Lab Manager, Ben Sawyer, in University of Central Florida Psychology Department by phone at 407-823-4344 or by email at sawyer@knights.ucf.edu.

IRB contact about your rights in the study or to report a complaint: Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (UCF IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact: Institutional Review Board, University of Central Florida, Office of Research & Commercialization.

12201 Research Parkway, Suite 301,
Orlando, FL 32826-3246
(407) 823-2901

You may also talk to them for any of the following:

• Your questions, concerns, or complaints are not being answered by the research team.
• You cannot reach the research team.
• You want to talk to someone besides the research team.
• You want to get information or provide input about this research.

Withdrawing from the study: If you decide to leave the research, you are free to do so at any time. If you signed up through the UCF SONA system you will receive an excused absence. The person in charge of the research study or the sponsor can remove you from the research study without your approval if you are under the age of 18. The sponsor can also end the research study early. We will tell you about any new information that may affect your health, welfare or choice to stay in the research.
References


