COUNTERING TASK-INDUCED COGNITIVE FATIGUE VIA ROTATION OF TASKS WITH CONTRASTING RESOURCE DEMANDS

A Dissertation

by

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ABSTRACT

Fatigue is a serious problem due to its high degree of prevalence and its critical effects on safety-related performance in multiple occupational settings. In more developed economies, the problem of fatigue has increasingly become one of cognitive rather than physical fatigue due to the changing nature of many jobs. Several countermeasures to the problem of fatigue are currently in practice, with one of the most common being the use of rest breaks. In physically demanding jobs, task rotation has shown to be another effective countermeasure with the added benefit of maintaining high worker productivity as compared to taking rest breaks. While the use of task rotation has been explored in terms of benefits to physical fatigue and emotional well-being, very little research has investigated the use of task rotation to lessen cognitive fatigue. This research work, therefore sought to explore the use of this countermeasure towards tasks prone to cognitive fatigue. Vigilance tasks are one category of tasks with a well-established history of leading to fatigue, which is specifically labeled as the vigilance decrement. Vigilance tasks were therefore chosen as the type for which the countermeasure of task rotation was investigated.

In order to explore the effectiveness of task rotation, a series of experiments were conducted which made use of groups performing different tasks in-between two periods of vigilance task performance. The groups differed in terms of the task performed during the middle “intervention” period to allow for the comparison of the relative effectiveness

of each of the tasks (defined by their task demands) as a countermeasure to the vigilance decrement.

While the initial experiments were conducted with basic laboratory-type tasks, the final study sought to explore the use of the task rotation countermeasure within a more applied setting, specifically a simulated semi-autonomous driving environment.

Overall, findings from both the basic and applied experiments supported the use of task rotation as an effective countermeasure to cognitive fatigue, specifically cognitive fatigue brought about by the performance of a vigilance task. In terms of the model of task demands considered by the experiment, the contrasting of the dimension of predominant processing stage appeared to be the most significant contributor to the effectiveness of the task rotation as a countermeasure for a vigilance task.

DEDICATION

This dissertation is dedicated to my wife and daughter who were my main motivation for seeing it to completion.

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Contributors

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NOMENCLATURE

HR	Heart Rate
HRV	Heart Rate Variability
MAST	Multi-Adjacent State Task
MRT	Multiple Resource Theory
NASA-TLX	National Aeronautics and Space Administration-Task Load Index
RAT	Remote Associates Test
RMSSD	Root Mean Square of Successive Heartbeat Differences
VAVT	Verbal Auditory Vigilance Task

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1. INTRODUCTION

The principal goal of this dissertation is to investigate how switching between tasks with different cognitive demands impacts cognitive fatigue. The cognitive demands framework used for this assessment was the multiple resource theory (MRT) (Wickens, 2008). The specific type of cognitive fatigue in focus for this research was that which is brought about by the performance of a sustained attention task, also known as the vigilance decrement. This research applies to jobs requiring sustained attention, particularly those in the area of transportation.

1.1. Motivation

The motivation for this dissertation is to provide new insights into how jobs can be designed so as to lessen cognitive fatigue. Historically, industrial engineers and other designers of jobs were primarily concerned with physical fatigue due to work. Methods were and continue to be developed to guide the design of jobs so as to lessen physical fatigue. As work in many developed countries has become less physically demanding and more cognitively demanding, similar methods need to be explored to lessen cognitive fatigue. The type of fatigue which is the focus of this research is task-induced cognitive fatigue, that is, fatigue brought about by the performance of a particular task. Given the broad range of tasks and their associated fatigue effects, this research specifically focuses on cognitive task fatigue due to sustained attention tasks, also

referred to as vigilance tasks. The fatigue brought about by these tasks is referred to as the vigilance decrement.

One of most widespread tools used in the designing of physical jobs so as to lessen fatigue is task rotation. The main principle behind task rotation is that rotating to a task which places demands on different body parts (e.g., shoulders, wrist, back) gives the body part used in the prior task time to recover while still allowing the worker to be productive. While the use of task rotation for tasks which are more cognitively demanding has been explored in the area of industrial and organizational psychology, the focus has mainly been on increasing motivation. In addition, the definition of what makes one cognitive task "different" from the next lacks some precision. In the area of cognitive human factors, the multiple resource theory (MRT) (Wickens, 2008) provides a classification system which can be used to define the differences between cognitive tasks. The idea of using task rotation between tasks of different demands (as defined by MRT) so as to lessen cognitive fatigue still needs to be explored. This research aims to investigate this approach with the specific focus being on the lessening of the vigilance decrement.

The transportation industry is one area prone to cognitive fatigue, which can have critical safety implications. Many jobs involving the operation of vehicles can be considered vigilance jobs in that the driver is required to monitor a continuous stream of stimuli while remaining alert enough to react to infrequent critical signals (e.g., obstacle in the vehicle's path). With the rise in the use of automation in the operation of vehicles, the role of the driver becomes even increasingly more of monitoring the performance of

the automation – arguably a task requiring more vigilance than just operating the vehicle without automation.

This research will first explore the use of task rotation between a vigilance task and a "different" task within a basic experimental setting. Several experiments in this level of control will be performed to better determine which aspect of "different" leads to the rotation task being effective in reducing the vigilance decrement. Being informed by the findings from the controlled environment, this research will then seek to apply the task rotation approach to the more realistic, yet still controlled setting of a simulated semi-autonomous vehicle. Findings from all experiments will be used to draw conclusions concerning the theory of fatigue (specifically the vigilance decrement) and the application of task rotation to real-world jobs with high cognitive demands.

1.2. Contributions

This dissertation further expands our understanding of cognitive fatigue, specifically fatigue brought about by the performance of a sustained attention (vigilance) task. The degree to which each of the "different" tasks is effective at lessening the vigilance decrement provides insight into the cognitive processes involved in each of these tasks as well as their interaction with each other. Findings from the simulated semi-autonomous vehicle experiment will provide insight on the feasibility of task rotation for lessening fatigue due to the operation of vehicles with autonomous elements. Hopefully this research will inspire further exploration into how job design can make use of task rotation to lessen the cognitive fatigue occurring during the performance of jobs.

1.3. Organization of this Dissertation

This dissertation begins with a review of relevant literature so as to provide important background information and demonstrate the need for research in this area. Next, the research questions which guided this work will be presented, followed by an explanation of the approach used to answer them. The experiments making up this approach will then be elaborated on in more detail separately. Finally, the conclusion from this body of research work will be discussed.

2. LITERATURE REVIEW

While it seems that most people have no apparent difficulty determining whether or to what extent they are fatigued, the actual meaning of what it is to be fatigued is more ambiguous. Concepts or terms associated with fatigue include tiredness, sluggishness, sleepiness, exhaustion, depletion, boredom, apathy, distraction, and stress.

Since the focus of this research is on cognitive fatigue, the concept of physical fatigue will be excluded. This literature review will therefore seek to define cognitive fatigue, taking into account multiple viewpoints of this concept. Next, a discussion will be covered on the specific type of task-induced cognitive fatigue analyzed in this research – the vigilance decrement. While perhaps somewhat better understood than the broader concept of fatigue, there still exist varying opinions on the underlying causes of the vigilance decrement. As with cognitive fatigue, a brief overview of some of these viewpoints will be covered before explaining the choice of the definition used in this research work.

As this research seeks to make use engineering principles towards solving problems in application settings, several example vigilance environments will be discussed. While this research work seeks only to apply the findings within a partially automated driving environment, awareness of additional vigilance environments provides further motivation for this line of research, as well as direction for future research efforts.

For this research work, the primary measure of the effects of fatigue is task performance. For fatigue related to the performance of vigilance tasks (the vigilance

decrement), specific well-defined measures of performance will be discussed, along with examples of how they are applicable to real-world tasks. Discussion of measures specific to the driving environment will be discussed in the methods section of the applicable experiment.

To supplement the analysis of fatigue and the effectiveness of countermeasures, in addition to task performance measures, subjective ratings of fatigue-related measures as well as relevant physiological measures will be collected during the experiments. Background information on the justification for the measurements chosen as well as their theoretical interpretations will be provided in this review.

Finally, as this research seeks to make use of the countermeasure of task rotation toward the lessening of cognitive fatigue, background information regarding the use of task rotation will be provided, along with its comparison with other commonly used countermeasures to fatigue. Task rotation implies that the new task is one which is "different" from the previous task. Critical to the assumption of this research work concerning the effectiveness of task rotation as a countermeasure to fatigue is the framework used to define what makes two tasks "different". Therefore, included is a discussion of the framework adopted by this research work for classifying tasks based on the cognitive demands they place on an operator.

2.1. Fatigue

Many attempts have been made to define, describe, or characterize the concept of fatigue. Some of the defining attributes given to fatigue include reduced "capacity and

desire to react" (Hancock et al., 2012), an "awareness" of decreased capacity (Aaronson et al., 1999), a "feeling" of exhaustion or decreased motivation (Salomone et al., 2021), a reduction in alertness (Borragán et al., 2017), a decrease in performance while sustaining effort (Walker et al., 2012), an "aversion" to continuing goal directed work, along with a "strong desire for rest" (Hancock et al., 2012), and "a subjective lack of mental energy" (Wylie et al., 2017).

Its root cause has been theoretically attributed to a decrease in energy due to performing work (Rabinbach, 1992), "an imbalance in the availability, utilization, and or restoration of resources" (Aaronson et al., 1999), "the depletion of attentional resources" due to performing a task (Ackerman, 2011), and prolonged exertion leading to the "psychobiological state" of fatigue (Meeusen et al., 2021).

Although these definitions and underlying causes have been put forth, "even today, there is no widely accepted view of what fatigue is, no mature theory of its origins and function …" (Hockey, 2013). So, while there is not a consensus on the definition of fatigue, the following a framework will be adopted to allow for the testing of hypotheses.

> ***Cognitive fatigue*** will be defined as a **signaling mechanism** (Hockey, 2013) informed by subconscious **cost-benefit analysis** (Kurzban et al., 2013) used to guide human behavior, specifically, to **compel the human to stop** what they are currently doing **and instead do something else** (Bartley, 1965), which is manifest in a variety of **physiological changes** (Nilsson et al., 1997) and a **decrease in energetic arousal**

(Desmond et al., 1998), experienced as **subjective fatigue** (Wylie et al., 2017) as well as a **drawing of attention away** (Warm et al., 2008) from the current behavior, which is placing an unfavorable **cost** on mental resources, towards behavior determined to be more **rewarding**.

This behavior deemed more rewarding, which may include **rest** (Hancock et al., 2012), allows the **mental resources** having been used the opportunity to **renew** or **recover** (Helton & Russell, 2015; Reinecke et al., 2011). **Self-regulation**, requiring **effort**, can resist the reorientation of attention, but not endlessly, as available effort will eventually be **depleted** (Inzlicht & Schmeichel, 2012).

2.2. Vigilance

Although this research is only focused on task-induced cognitive fatigue, this still leaves open a broad space of possible exploration. As will be explained, tasks can be categorized in terms of the cognitive demands they place on the human. This, along with the premise that cognitive fatigue is "specific" rather than "general" (Hockey, 2013), motivates this research work to focus on cognitive fatigue brought about by a specific type of task. Due to the proven decrement in performance and accompanying feelings of fatigue when performed for extended periods, vigilance tasks were chosen as the focus of this research.

> "**Vigilance** or **sustained attention** refers to the ability of individuals to **monitor** a **continuous stream of stimuli** for **infrequent or occasional critical targets** over time" (Ross et al., 2014).

Vigilance tasks, therefore, are ones which "[require] the detection of changes in a stimulus during long monitoring periods when the subject has little or no prior knowledge of the sequence of the changes" (Olmedo & Kirk, 1977).

The concern with vigilance tasks has to do with the typical decline in human performance over time, in terms of a decrease in signals detected and an increase in response time, which is known as the vigilance decrement (Helton & Russell, 2015). The vigilance decrement typically occurs within 15 minutes of the start of the task, but in highly demanding tasks, it can occur within 5 minutes (Warm et al., 2008). In addition to the performance decrement, carrying out a vigilance task for an extended period of time has been shown to cause stress (Warm et al., 2008) as indicated by subjective measurements.

Historically, human factors researchers considered vigilance tasks to place only a low mental demand on operators, as described in the review by Warm et al. (2008). Researchers following this theory believe that the vigilance decrement is due to the monotony of the task, which causes the mind to be underloaded. This underloading is believed to lead to a decline in arousal due to under-stimulation, as well as cognitive task disengagement, which explains the decline in performance.

The more popular view today, however, is that the vigilance decrement is due to a depletion in cognitive resources (resource depletion theory) and fatigue due to the continuous processing required by the task (overloading) (Helton & Russell, 2015). Warm et al. (2008), point to behavioral, neural, and subjective data as evidence for this theory. Lee et al. (2017) also believe that vigilance tasks in low-arousal environments can require a high level of mental effort and lead to just as much fatigue as a high-workload situation.

In summary, there is disagreement over whether the vigilance decrement is due to underload because of the monotony of the task, which results in cognitive disengagement, or overload because of the continuous processing required, which results in mental resource depletion and fatigue. The theory of vigilance decrement taken for this research, however, is somewhat of a combination of these two theories.

In typical vigilance tasks, attention is not drawn naturally to the task stimuli since neither stimuli novelty nor other similar mechanisms are at work. And while a simple cognitive and motor response is needed on the rare occasions when a signal is detected, the cognitive resource demands of the task theoretically fall nearly entirely on the perception stage and are usually exclusive to a single modality and code. These characteristics explain why vigilance tasks are often described as being boring and thought to place a low cognitive demand on the human.

However, high performance on a vigilance task requires near-constant conscious attention directed at the task stimuli in order to detect/discriminate signals from non-signals. That is, near-constant use of the perception resource is required. In order to

maintain this attention on the task, which is intrinsically non-rewarding yet attentionally demanding, constant self-regulation, specifically top-down attentional control, is required. However, maintaining this attentional control requires effort and is highly demanding, leading to feelings of stress, which matches reported subjective measures. Self-regulatory power is a limited resource which depletes when used continuously for long periods of time. Over time, as effort and self-regulation decrease, attentional control breaks down, which leads to lapses in conscious attention to the stimuli and required cognitive processes. These lapses of attention then result in decreased performance.

The concept of activation (arousal) is also key for understanding the vigilance decrement according to this theory. Langner and Eickhoff (2013) point to evidence that continued vigilance performance leads to a decrease in "energetic arousal", but an increase in "tense arousal", which is a reference to Thayer's (1978) two-dimensional arousal model. This aligns with commonly reported subjective measures of feelings of drowsiness (Batista, 2007) yet also stress (Warm et al., 2008). Thayer (1978) points out that while there are several physiological measures of arousal, most can be indicative of either of the arousal dimensions, which creates difficulties for interpretation.

Other researchers, considering only a single dimension of arousal, have identified relationships between it and cognitive behavior. Arousal has been conceptualized as "physiologic and behavioral construct, which is related to the degree of excitation or [attention] mobilization" and therefore arousal can be defined behaviorally as "a supplier of attentional resources to the perceptual level of information processing" (Laures et al., 2003). For vigilance tasks, high levels of attentional resources are needed for the

detection of stimuli. Thus, the decrease in arousal brought about by performance of the vigilance task produces a behavior which is antagonistic to continued vigilance performance. In addition to impacting attention, low arousal may also affect other cognitive behaviors which could impact task performance. For example, Kahneman (1973) states "... a state of extremely low arousal may cause: (1) a failure to adopt a task set; (2) a failure in the evaluation of one's performance, resulting in an insufficient adjustment of the investment of capacity to the demands of the task."

Based on this theoretical framework of vigilance put forth, characteristics of an intervening task which is likely to be effective in counteracting the vigilance decrement are proposed. Specifically, the intervening task should be one which: (1) places cognitive resource demands on the human which are different than those of the vigilance task, (2) leads to an increase in arousal when performed, (3) naturally draws attention to itself and/or is intrinsically rewarding, and therefore (4) does not require as much top-down attentional control (self-regulation), and hence (5) requires much less effort.

While not all researchers appear to classify the vigilance decrement as a form of cognitive fatigue, it can be seen that the above theory of vigilance fits within our chosen framework of fatigue. Over time, the subconscious cost-benefit analysis determines the task to have a high attentional cost, along with an inadequate reward. Attention is naturally drawn away from the task and can only be maintained on the task by making an effortful attempt of self-regulating (top-down controlling) one's attention. In addition to loss of attention to the current task, our framework of fatigue also includes physiological changes and the related experience of subjective fatigue. The vigilance

decrement meets this condition also in that changes occur in arousal levels which are reflected in physiological changes and felt as drowsiness and stress.

2.3. Vigilance Environments

Many jobs today require workers to perform what can be considered vigilance tasks, including product inspection, security weapon detection, radar monitoring, tumor detection on X-ray output, air traffic control, and hazard detection while driving (Lee et al., 2017). Many of these tasks have serious safety implications, therefore necessitating a maintenance of high performance.

Although there is much variation in the demands of different tasks such as these, they share several of the same task characteristics which make them all be considered vigilance tasks. Most are performed continuously for prolonged periods of time, with the appearance of low demands required by the task. However, as it was discussed when defining fatigue, the tasks do require a high level of attention focused on particular task-relevant stimuli. The effects of fatigue usually do not emerge right away and can be confounded with the effects of the need for sleep. A critical effect of fatigue often seen is a drop in task performance. As will be discussed in the next section, performance on many of these tasks can be classified into one of several abstract forms.

2.4. Performance Measures

Four of the most common measures of vigilance task performance are detection rate (DR), false alarm rate (FR), response time (RT), and sensitivity (d’). Detection rate

is defined as the proportion of signals detected. As an example within the context of a product inspection task, a defective part would be considered a signal. If over the course of a shift, an operator detected 12 out of 15 defective parts which passed through their station, then their detection rate would be 12/15 = 0.8. As demonstrated by this example, a higher detection rate is indicative of better performance on a vigilance task.

In reference to the next measure, a false alarm occurs when an operator responds to a non-signal in a manner only required toward the signals. False alarm rate, therefore, is defined as the proportion of non-signals which are responded to by an operator. So, in the product inspection context, if 100 passing-quality parts went through an operator's station and four of these were incorrectly discarded as defective parts, then the operator would have a false alarm rate of 4/100 = 0.04. For false alarm rate, a lower value is indicative of better performance.

Response time is defined as the time between the appearance of a signal and the response to that signal by the operator. As an example in the driving environment, the sudden braking of another vehicle in front of a driver's path can be considered a signal requiring a response from the driver, such as the braking of their own vehicle. For this example, the response time can be defined as the time from when the vehicle in the front braked until the time when the driver in the rear vehicle braked. Since overall task performance is often dependent on how quickly the operator responds to signals that occur, a lower response time is indicative of better performance.

Sensitivity is a measure of how good an operator is at discriminating a signal from a non-signal (Lee et al., 2017). One specific measure of sensitivity, d', is defined

mathematically as the inverse normal transform of the false alarm rate, subtracted from the inverse normal transform of the detection rate (Hautus, 1995).

$$d' = Z(DR) - Z(FR)$$

The sensitivity measure will be higher when the detection rate is higher and when the false alarm rate is lower. So, in following with the definitions of better performance for each of these measures, a higher sensitivity score is indicative of better performance. As will be discussed in the experiment methods section, if the detection rate or false alarm rate is either zero or one, then d' cannot be calculated, and therefore a corrected form of this measure must be used instead.

For the final experiment, which took place within the applied setting of a simulated driving environment, the measure of lane deviation was also collected. Although not considered a strict measure of vigilance, lane deviation is often used as a measure of general driving fatigue when also testing for the vigilance decrement (Huang et al., 2020; James & Vila, 2015).

2.5. Subjective Ratings

In addition to objective performance measures, subjective measures of participants' perceived level of fatigue and related feelings are often used as supplementary measures which can be used to validate the performance measures as well as provide additional insights not provided by the performance measures. One of the most widely used subjective ratings tools is the NASA-TLX (Task Load Index) (Hart & Staveland, 1988). This survey tool can be used to collect data concerning the

perceived levels of overall workload, task difficulty, time pressure, performance, mental/sensory effort, physical effort, frustration, stress, fatigue, and activity type. A linear scale with bipolar labels at each end, designating “high” and “low” for each measure is used as the input mechanism. Based on the scale position of the input, values ranging from 1 to 100 are assigned to each measure. In addition to providing a scale input for each measure, participants perform pairwise rankings of measures in terms of their personal definition of workload. For this research work, an adapted version of the NASA-TLX instrument was used to collected subjective measurements from participants at various time points during the experiment.

2.6. Physiological Measures

Several physiological measures have been shown to be indicators of cognitive fatigue. Due to the particular availability of data collection equipment, this research work is focused on physiological measures of fatigue which can be collected through heart rate and eye movement measurements.

2.6.1. Heart Rate Measures

Prior research has identified certain heart rate patterns to be indicative of fatigue. Studies have shown that with an increase in mental workload, heart rate (HR) increases (Shakouri et al., 2018). Another commonly used heart-related measure is heart rate variability (HRV), which is “the variation in the time interval between heartbeats and provides information about central nervous system activity” (Rogado et al., 2009).

Heart rate and heart rate variability have been used to identify states of arousal and fatigue in fatigue-prone environments such as driving (Hartley et al., 1994; Lal & Craig, 2001). Specifically, it has been demonstrated that heart rate decreases over the course of monotonous driving tasks (Jagannath & Balasubramanian, 2014; Riemersma et al., 1977). Increases in heart rate variability have been connected with driving fatigue and decreases in driving performance (Harris & Mackie, 1972). However, heart rate variability has also been shown to decrease with increases in mental workload (Shakouri et al., 2018). The heart rate variability measure of the root mean square of successive heartbeat differences (RMSSD) has been shown to be one of the most robust time domain measures of workload (Shakouri et al., 2018).

2.6.2. Eye Movement Measures

Two commonly used measures of fatigue related to eye movements are blink rate and pupil diameter. An increase in the blink rate has been shown to be related to fatigue (Nilsson et al., 1997). In addition, an increase in eye closure duration has been linked to fatigue, as exemplified in the driving setting (Åkerstedt et al., 2005).

In regards to pupil diameter, an decrease in "stimulus-evoked pupil dilation" has been shown to occur with increasing mental fatigue (Hopstaken et al., 2015). A decrease in pupil diameter has been shown to be associated with decreases in vigilance performance (Abe et al., 2011). Pupil diameter measured using an eye tracker was shown to significantly decrease over the course of the experiment, corresponding to increasing levels of fatigue (Körber et al., 2015).

2.7. Fatigue Countermeasures and Task Rotation

A common countermeasure to task-induced fatigue is the use of rest breaks (Hancock et al., 2012; Tucker, 2003). Rest breaks have been employed with success in both physically-demanding tasks (Dababneh et al., 2001) and cognitively-demanding tasks (Henning et al., 1997). In their meta-analysis of rest breaks, Wendsche et al. (2016) concluded that rest breaks have a positive effect on both quality and quantity measures of task performance. There is evidence that frequent rest breaks may improve safety, such as during long night shifts (Folkard & Tucker, 2003). The recognized importance of having workers stop their current task and rest is reflected in federal regulations such as the Federal Motor Carrier Safety Administration (FMCSA, 2015) setting driving limits of 11 hours per day and 70 hours in an 8-day period for long haul truck drivers. Several long-term positive effects of rest breaks have also been demonstrated for both individuals and organizations. For example, sufficient rest breaks eliminated the association between long working hours and risk of various health problems for workers (Park et al., 2019). Furthermore, the utilization of rest breaks has been shown to improve employee retention (Wendsche et al., 2017).

A significant issue with rest breaks, however, is their cost in the form of lost productivity. In their review, Wendsche et al. (2016) calculated that on average, rest breaks reduce working time by 9.3%. Labor productivity can be defined as output per unit time (Konz & Johnson, 2018), and so while time passes without output occurring, overall productivity decreases. In long-haul trucking, drivers are typically paid by the number of miles they drive their freight (Belzer & Sedo, 2018). Therefore, in

occupations such as trucking, rest breaks are certainly seen as a cost. This viewpoint is likely reflected in the behavior of truck drivers. Despite the existence of the previously stated driving time regulations, it has been reported that 70.5% of drivers exceeded the 11 hours per day driving limit, with 38.3% even exceeding 13 hours per day (Lemke et al., 2021). This behavior is not without risk, however. Driving for long durations has been shown to impair driver alertness and performance, therefore making it a significant cause of fatigue-related accidents on major roadways (Ting et al., 2008).

Another common countermeasure to task-induced physical fatigue, and one which still allows workers to stay productive is the use of task rotation. For clarification, the terms “task rotation” and “job rotation” are often used interchangeably and lack prevailing definitions (Mlekus & Maier, 2021). However, usage trends suggest that task rotation occurs over shorter time intervals [hour, day, or week scale] than does job rotation [month, quarter, or year scale]. Both task and job rotation, however, differ from task switching (Jamadar et al., 2015), which typically takes place on the second or minute time scale. The term “task rotation” therefore is used in the description of this research work as it implies a time scale most closely matching that of the experimental conditions utilized.

Even as many jobs in developed countries have become less physically demanding, the use of task rotation is still fairly widespread. For example, a survey of manufacturing companies showed that 42.7% made use of rotation (Jorgensen et al., 2005). Task rotation has also been adopted for reasons other than physical wellbeing, as studied in the field of industrial and organizational psychology. Companies have introduced it for

purposes of reducing boredom, increasing motivation, and promoting learning (Eriksson & Ortega, 2006). Despite its prevalence for the purposes of reducing physical impairment and improving general employee wellbeing, task rotation does not appear to be sufficiently investigated as a countermeasure to cognitive fatigue. In his extensive review of cognitive fatigue research Hockey (2013) observes that "...the value of varied work has long been recognized in industrial psychology, although this insight has not been explored fully by more recent research on task performance." Hockey (2013) further elaborates on this observation:

> *"Oddly the question of recovery from fatigue, and whether a change of task might be as effective as a complete rest, appears to have been largely ignored by modern research. Yet it presents rich opportunities for research on fundamental mechanisms of human performance … there are no comparable studies on what conditions of changed work are effective for recovery."*

While as a psychologist, Hockey appears to primarily be interested in this question for the sake of further insight into our understanding of human cognition, it is also a potential opportunity for industrial engineers to rethink how work is designed so as to lessen task-induced cognitive fatigue without the loss in productivity which comes with passive rest breaks. A passive rest break is essentially one in which the person is not required to perform any task, either mentally or physically. In the strictest use of the term, such as in controlled experiments, the participant is told to sit quietly and do

nothing for a specified amount of time (Finkbeiner et al., 2016). The main question this research seeks to investigate, therefore, is ***what is the effectiveness of task rotation as a countermeasure to task-induced cognitive fatigue***?

2.8. Framework for Classifying Task Differences

The idea of a task change implies that the new task is different from the previous one in some way, but this needs to be more precisely defined. For physical tasks, categorizations of movements and static positions have been made which allow for the selection of rotating tasks to be ones which place demands on different biomechanical subsystems (Konz & Johnson, 2018). Somewhat analogous to these physical subsystems, frameworks have been developed to categorize cognitive processes. One of the most popular of these frameworks is the multiple resource theory (MRT) (Wickens, 2008), which is summarized in the model shown in Figure 2.1.

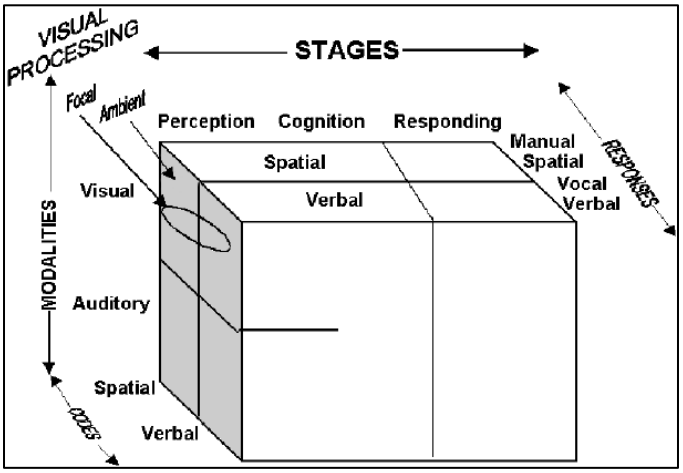

Figure 2.1 Multiple resource model (Wickens, 2008)

The model conceptualizes human cognition using several dimensions, including stages of processing (perception, cognition, and responding), codes of processing (spatial and verbal), and perceptual modalities (visual and auditory). Human performance studies have validated the separateness of these resources, while additional validity is provided by the neurophysiological plausibility of the dimensions (parallels in brain anatomy) (Wickens, 2008). One of the main uses of this model has been to inform multitask design, that is, to design each of the different tasks so that they are not competing for the same resources (Yang & Ferris, 2020). However, just as this model serves as a framework for defining "separateness" of resources engaged in multitasking, it can also be used as a framework for defining "different" in task switching.

3. RESEARCH QUESTIONS

The information gathered from prior work points to a gap in the research and an opportunity to explore research questions which will have an impact in both the theoretical understanding of task-induced cognitive fatigue, specifically the vigilance decrement, and the practical application of countermeasures.

This research focused specifically on the countermeasure of task rotation to determine its degree of effectiveness and also to determine the degree to which specific task characteristics (the cognitive demands of the task) impact the overall effectiveness of the task rotation.

This body of research work therefore seeks to answer the following questions.

3.1. Research Question 1

After performing a vigilance task for a period of time, what is the comparative impact of each of the following interventions on future performance when the vigilance task is resumed?

1) **continuous vigilance task performance**
2) **rotating to a task of contrasting cognitive demands**
3) **passively resting**

And if the task rotation proves superior to the alternative interventions, then:

3.2. Research Question 2

To what extent is the performance impact of the task rotation affected by the contrasting demand of the **perceptual modality**?

3.3. Research Question 3

To what extent is the performance impact of the task rotation affected by the contrasting demand of the **processing code**?

3.4. Research Question 4

To what extent is the performance impact of the task rotation affected by the contrasting demand of the **predominant processing stage**?

3.5. Research Question 5

How do the findings from questions 1-4 scale up to a more complex and realistic task environment? Specifically, after a period of continuous semi-autonomous highway-type driving, what is the comparative impact of each of the following on (a) driving-related performance, as well as (b) physiological and (c) subjective measures of fatigue once the driving task is resumed?

1) **continuous driving**
2) **rotating to a task of key contrasting cognitive demands (informed by question 1-4 findings)**
3) **passively resting**

4. APPROACH

This dissertation is composed of multiple experiments, organized by the research question they were designed to address.

4.1. Experiment for Question 1

The first experiment was designed to determine the relative impact that performing different tasks during an "intervention period" has on vigilance task performance once the vigilance task is resumed. The experiment made use of three groups, each of which performed the vigilance task for the first period. For the second period, also known as the intervention period, each group of participants performed a different task. The first group continued to perform the vigilance task without stopping between the periods, the second group rotated to a task of contrasting cognitive demands, and the third group took part in a passive rest break. Following the end of the intervention period, all three groups resumed, or continued the vigilance task. Measures of vigilance task performance as well as subjective measures of fatigue were taken during the experiment. Differences in measures from pre- to post-intervention period were analyzed to determine the impact of performing each of the different tasks during the intervention period.

The task of contrasting cognitive demands was chosen to be one which contrasted from the vigilance task in terms of perceptual modality, processing code, and predominant processing stage (in reference to Wickens' (2008) multiple resource

model). Since later experiments will also make use of task rotation using other tasks, the phrases “original task rotation” and “original intervening task” will be used to refer to this first task of contrasting cognitive demands.

4.2. Experiment for Question 2

After results from the first experiment demonstrated that rotation to a task of contrasting demands can be an effective countermeasure to the vigilance decrement, additional experiments were needed to determine the degree to which the effectiveness was due to each of the contrasting dimensions (modality, code, and predominant processing stage). To isolate the impact that the contrast in perceptual modality had on the effectiveness of the original intervening task, a fourth group was added which rotated to a task which contrasted from the vigilance task in terms of only processing code and predominant processing stage, but not perceptual modality.

4.3. Experiment for Question 3

Similar to the experiment for Question 2, this experiment was designed to isolate the impact of one specific contrasting dimension of the original intervening task. For Question 3, a fifth group was added which performed a task which contrasted from the vigilance task only in terms of perceptually modality and predominant processing stage, but not processing code. This group was added to allow for comparative analysis with the effectiveness of the original intervening task so as to isolate the impact that the contrast in processing code had on the effectiveness of the original intervening task.

4.4. Experiment for Question 4

A sixth and final group was added to allow for comparative analysis so as to determine the isolated impact that the contrast in predominant processing stage had on the effectiveness of the original intervening task. This sixth group, therefore, rotated to a task which contrasted in cognitive demands from that of the vigilance task in terms of only perceptual modality and processing code, but not predominant processing stage.

The experiments for Questions 2, 3, and 4 were each an extension of the experiment for Question 1 in that an additional group was added for each question in order to isolate the impact of the effectiveness of one particular contrasting dimension of the original intervening task. The participant data from the Question 1 experiment, along with new data from the additional groups was used for the analysis to address Questions 2, 3, and 4. After the analysis for Question 1, the next analysis was not performed until all groups had been added, so as to address Questions 2, 3, and 4 together.

4.5. Experiment for Question 5

Following the demonstrated effectiveness of task rotation as a countermeasure to the vigilance decrement within a basic experimental setting, a final experiment was designed to implement the task rotation countermeasure within a more applied setting, specifically the driving environment. The driving environment used for this experiment was a simulated semi-autonomous vehicle highway scenario, which in addition to the lane maintenance task, also included the performance of an artificial vigilance task designed to imitate the detection of vehicle sensor signals.

Similar to the previous experiments, this experiment made use of multiple groups, each of which performed the driving task for the first period. For the second period (intervention period), each group of participants performed a different task. The first group continued to perform the driving task without stopping between the periods, the second group rotated to a task of contrasting cognitive demands, and the third group took part in a passive rest break. Following the end of the intervention period, all three groups resumed, or continued the driving task. Measures of driving task performance, subjective measures of fatigue, and physiological measures of fatigue were taken during the experiment. Differences in measures pre- and post-intervention were analyzed to determine the impact of performing each of the different tasks during the intervention period.

As with the original intervening task used in the basic experiment, the task of contrasting cognitive demands was chosen to be one which contrasted from the driving vigilance task in terms of perceptual modality, processing code, and predominant processing stage (in reference to Wickens' (2008) multiple resource model). However, unlike the tasks used in the experiments for Questions 1-4, the rotation task for Question 5 was chosen to be one which, like the driving task, was more applied in nature. The rotation task used in this final experiment sought to imitate the task of an information helpline operator.

5. EXPERIMENT FOR QUESTION 1

5.1. Hypotheses

It was expected that all groups would see a decrease in vigilance task performance from pre- to post-intervention, following the assumption that the impact of the vigilance decrement would increase over time even for the groups which performed an intervening task or rested. The greatest vigilance decrement was of course expected for the group which performed the vigilance task continuously, with a lesser decrement expected for the intervening task group and the rest group. One of the main comparisons this research sought to answer is whether the use of the intervening task was as effective as taking the rest break.

If fatigue is considered to be due solely to the depletion of cognitive resources as a whole (not considering the possible separateness of different resources), then it is expected that the rest break would be superior to the intervening task given that the intervening task continues to use cognitive resources, while the rest break theoretically uses minimal cognitive resources. If, however, the theory is held that different cognitive resources are separate, in that the use of one type does not impact the future availability of a different type, then we would not expect the rest break to be superior to the intervening task, assuming the intervening task truly uses cognitive resources which are different from those required by the vigilance task. The theory taken by this research work is that cognitive resources, for the most part, are indeed separate in that while

resources in use may become fatigued, separate resources (not in use) will not become fatigued.

In addition, if fatigue, particularly the vigilance decrement, is considered to be dependent on energetic and tense arousal, then it can be hypothesized that the intervening task may actually be superior to the rest break in this regard. This depends on the assumptions that while the rest break may decrease tense arousal, it will likely not increase energetic arousal, and that the novelty of the intervening task will raise energetic arousal, while not raising tense arousal. This research work follows the theory that fatigue does depend on arousal levels which are impacted by tasks performed, therefore the intervening task may be even more effective than the rest break in lessening the vigilance decrement. Figure 5.1 summarizes the hypotheses concerning changes in fatigue level over time between groups.

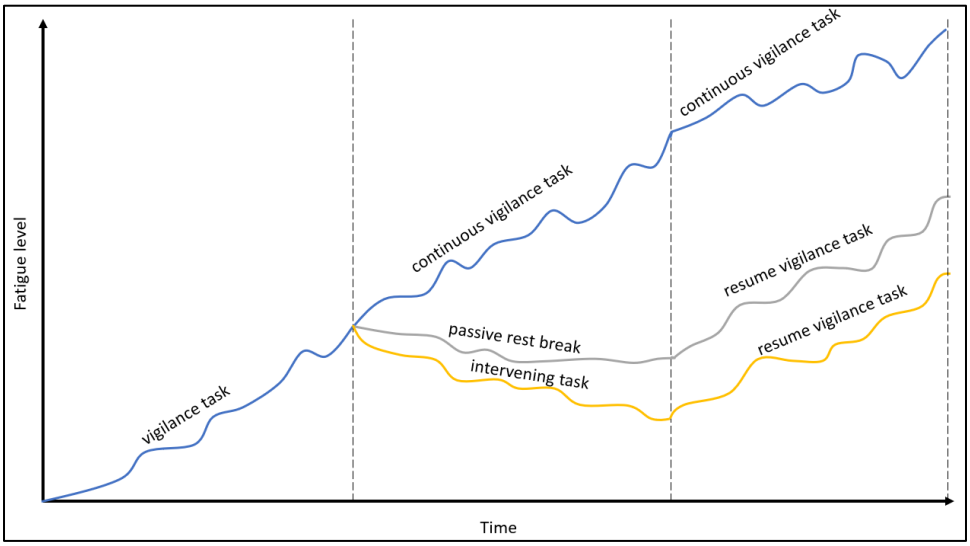

Figure 5.1 Hypothesized changes in fatigue between groups

While the above hypotheses dealt with the expected changes in vigilance task performance, certain trends are also expected for the subjective measures of fatigue. It is hypothesized that for the rest group and the group performing the task of contrasting demands, the post-task subjective measures of mental demand, perceived performance, and motivation will be higher than that of the continuous vigilance group, while the measures of effort, frustration, boredom, and mind-wandering will be lower than that of the continuous vigilance group. If a post-task change in physical demand and temporal demand is seen, it is expected to be lower for the rest group than the group performing the task of contrasting demands and the group performing the vigilance task continuously.

5.2. Methods

Before attempting to apply the proposed task rotation countermeasure to industry-type tasks, a basic experiment was conducted to test the fundamental hypotheses. In this experiment, participants were divided into three groups. All groups started by performing a vigilance task, specifically a version of the Mackworth clock test by means of the PEBL software (Mueller & Piper, 2014) (see Figure 5.2). This task involves watching a red dot move clockwise around a large circular shape. If the dot moves to the next space, then the participant should take no action, but if the dot skips a space, the participant should respond by pressing the spacebar as quickly as they are able. In this experiment, approximately 20% of dot movements were skips. A full dot

movement cycle lasts approximately one second, with the presence of the dot lasting approximately 0.6 seconds and the absence of the dot lasting approximately 0.4 seconds.

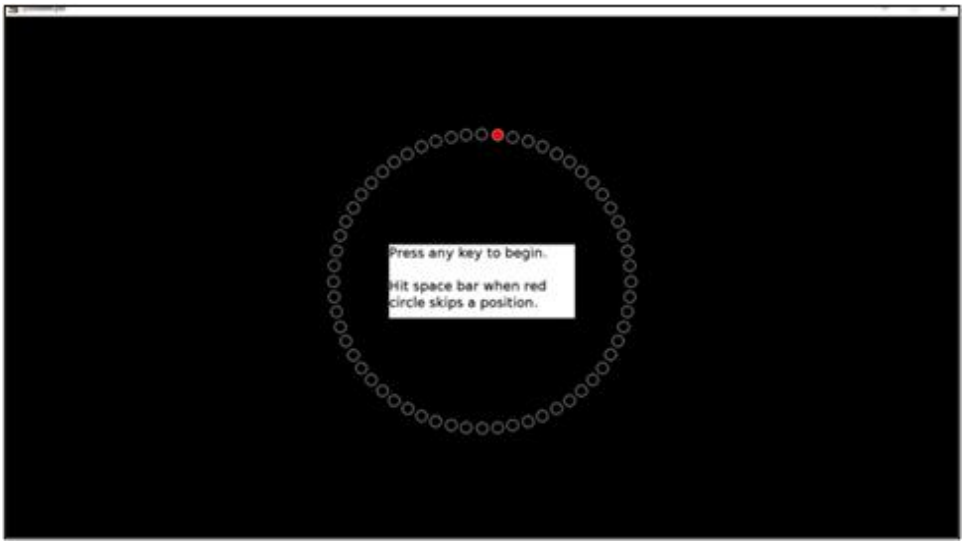

Figure 5.2 PEBL clock task screen

After 10 minutes (at which the vigilance decrement has been shown to occur), participants in each group began performing different tasks. Group 1 (vigilance only) continued to perform the clock test with no interruption. Group 2 (intervening task) stopped performing the clock test and rotated to performing an auditory version of the remote associates test (RAT) (Mednick, 1962) for 10 minutes. The RAT task is typically used as a test of creativity in which participants are given three seemingly unrelated words and are required to think of a fourth word which relates to them all. For example, the three given words could be “cream”, “skate”, and “water”, with the correct answer being “ice”. For this experiment, the words were presented auditorily. However, the interface used to play the sound recordings, as well as the instrument for recording responses did both require the use of the visual modality and the spatial code. Sound

files were embedded into a PowerPoint slide (see Figure 5.3). Participants hovered their cursor over the sound logo which would reveal a play button, which then needed to be pressed for the sound file to play. Participants recorded their answers by typing them into a response document provided to them (see Figure 5.4). Performance was scored in terms of (1) number of questions attempted and (2) number of questions correctly answered. Participants did not receive feedback on this task (they did not know which of their answers were correct or not).

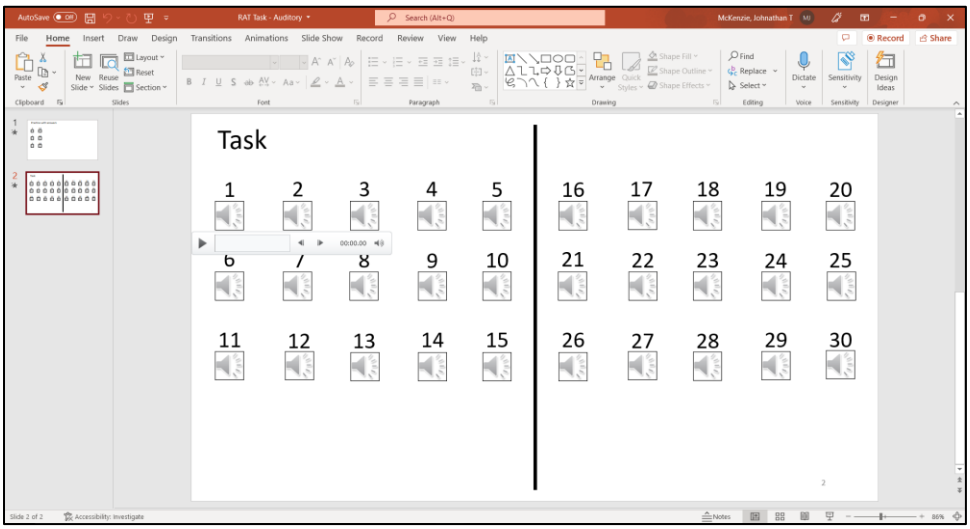

Figure 5.3 Auditory remote associates test (RAT) interface

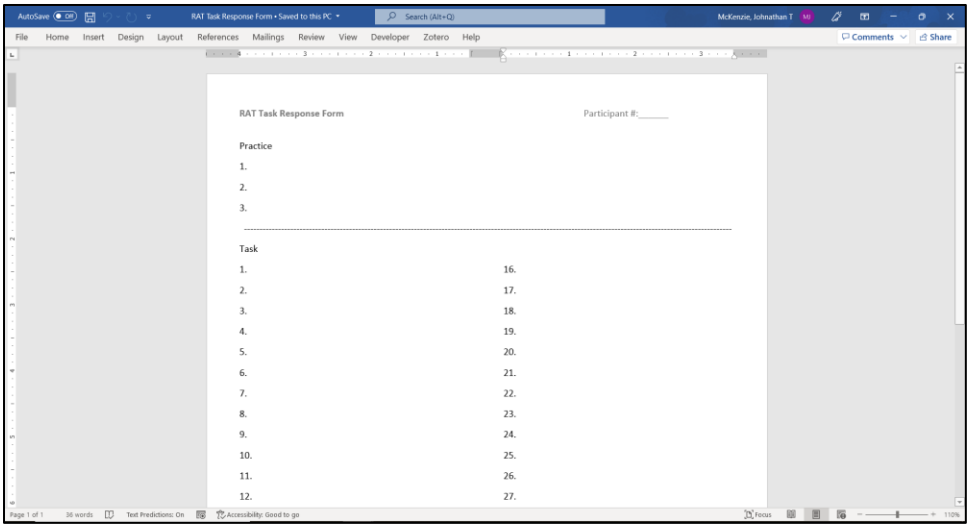

Figure 5.4 Remote associates test (RAT) response document (blank)

Previously, it was stated that based on our adopted theory of vigilance, an intervening task which is likely to be successful should be one which (1) places cognitive resource demands on the human which are different than those of the vigilance task, (2) leads to an increase in arousal when performed, (3) naturally draws attention to itself and/or is intrinsically rewarding, (4) does not require as much top-down attentional control (self-regulation), and hence (5) requires much less effort.

The RAT task was chosen as one which theoretically places demands which are opposite to those of the vigilance task. As discussed, vigilance tasks require simple detection or discrimination of the stimuli, along with a simple cognitive and motor response. Theoretically then, the cognitive demands of the task fall predominantly on the perception stage, with a smaller demand on the cognition and response stages. For the PEBL clock task, the demands are almost entirely on the visual modality and the spatial code. Figure 5.5 illustrates the theoretical demands of the clock task, with the blue

shading being darker on the perception stage, given its greater theoretical demand. The RAT, in contrast, theoretically imposes less of a demand on perception, but much more on the cognition stage. The modality of perception required is auditory rather than visual (with the exceptions explained above), and the code utilized is verbal instead of spatial (also with some exceptions). The contrast in the dimensions is illustrated in Figure 5.6.

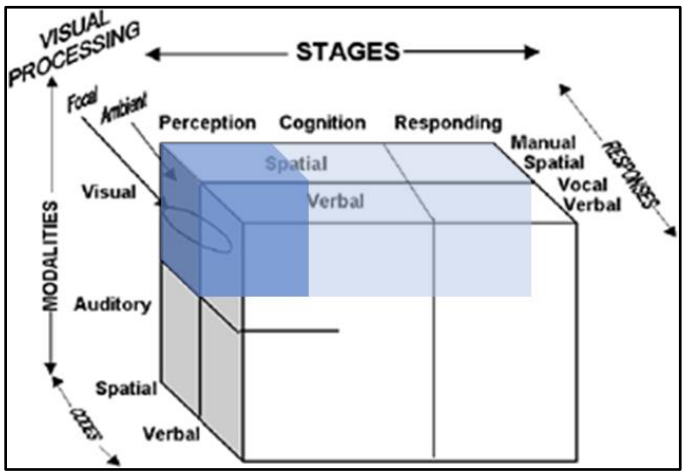

Figure 5.5 Theorized demands of the (vigilance) PEBL clock task represented by the blue shading (adapted from Wickens, 2008)

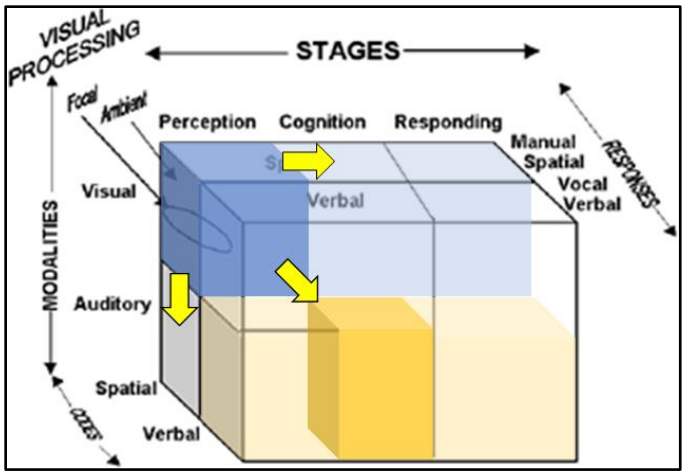

Figure 5.6 Theorized demands of the (intervening) RAT task represented by the yellow shading, with yellow arrows indicating the change of resource dimensions between tasks (adapted from Wickens, 2008)

Some research has shown the RAT task to be associated with divergent creative thinking (Wu et al., 2017). Other divergent creative thinking tasks have been shown to increase arousal levels (Amila & Umemuro, 2018), indicating that the RAT task may also have this effect. In addition, the RAT task has been described as "a very salient and interesting task" (McFarlin & Blascovich, 1984), thus we assume that it is a task which draws attention to itself. Previous research has also considered the RAT task to be intrinsically rewarding (Markman et al., 2007). Therefore, it is assumed that the RAT task does not require as much self-regulation and effort to perform as the vigilance task does. The combination of these characteristics makes the RAT task suitable for testing our theory of task rotation for vigilance tasks.

The last group, Group 3 (rest group), stopped performing the clock test after the first ~10 minutes and took a passive rest for 10 minutes, during which they were instructed to sit quietly and perform no actions (they could close their eyes if they

preferred). Theoretically, the task of passively resting should make no more than minimal cognitive demands on the participant.

For all groups, following the second ~10 minutes (intervention period), participants returned to (or continued with) the clock test for an additional ~10 minutes. Statistical comparisons were made of vigilance performance differences between groups from before to after the intervention period. Ninety-seven participants took part in this study, divided across the three groups. Due to COVID safety precautions, this experiment was conducted remotely. Thus, while performance data and subjective ratings were able to be collected, it was not feasible to collect physiological data.

In addition to collecting performance data, subjective ratings of fatigue and related measures were also taken at various points during the experiment. The ratings were collected via a Qualtrics survey which contained a sliding response question for each of the following measures: mental demand, physical demand, temporal demand, performance, effort, frustration, boredom, motivation, and amount of mind-wandering. The remote experiment instructions contained links for direct access to these surveys. Figure 5.7 shows a screenshot of one of the surveys, while Appendices L and M contain the full list of questions.

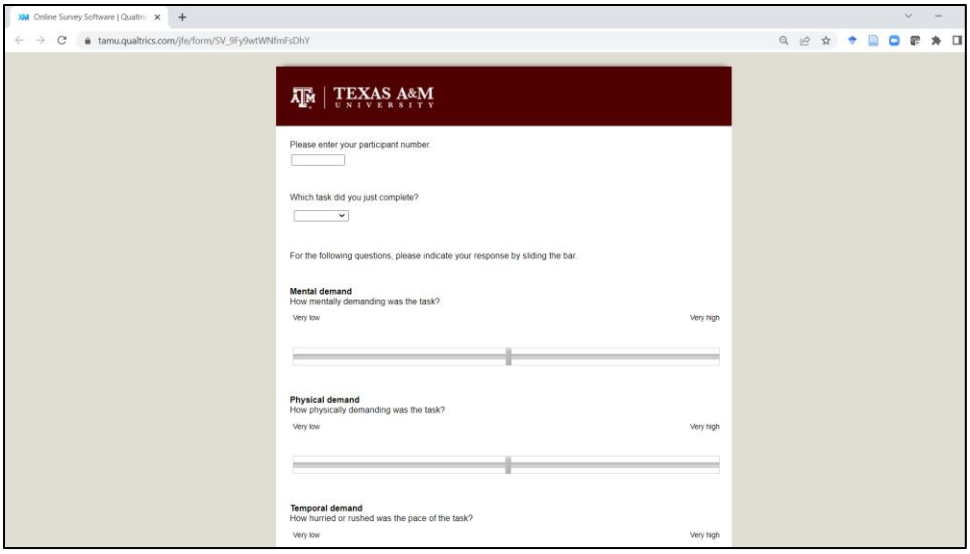

Figure 5.7 Screenshot of subjective ratings survey

All participants completed a subjective ratings survey prior to beginning the first 10 minutes of the vigilance task in order to record their baseline level of perceived fatigue and related measures. For this first (pre-experiment) survey, participants were instructed to answer "based on what you have been doing today before this experiment". For later surveys, participants were instructed to answer based on the task they just completed. The sliding bar input method gave as output a number between 0 and 100, corresponding to the far left and right of the sliding bar range respectively.

In addition to the subjective ratings surveys, participants also completed a basic demographics and work survey during the pre-experiment period. In addition to questions concerning age, gender, and education, other questions concerned the physical and cognitive demands of their typical work. Finally, they were asked about the demands of the tasks they performed prior to beginning the experiment, as well as their level of

alertness, recent substance consumption, level of hunger, and level of rest. The full list of these questions can be found in Appendix K.

To assist readers in following the series of steps (tasks and surveys) performed by each group, Table 5.1 provides a summary of this information. Note that the estimated times for each period are provided in the top row.

Table 5.1 Experimental steps by group (for Groups 1-3)

	~3 min	~3 min	*survey time (~2 + ~1 min)*		*~10 min + survey time*		*~10 min + survey time*		*~10 min + survey time*	
	Pre-Experiment (Period 0)				**Period 1**		**Period 2**		**Period 3**	
Group 1	clock task practice	intervening task practice	demographics survey	subjective ratings survey	clock task		clock task		clock task	subjective ratings survey
Group 2	clock task practice	intervening task practice	demographics survey	subjective ratings survey	clock task	subjective ratings survey	auditory RAT task	subjective ratings survey	clock task	subjective ratings survey
Group 3	clock task practice	intervening task practice	demographics survey	subjective ratings survey	clock task	subjective ratings survey	rest break		clock task	subjective ratings survey

Remote data collection was conducted by emailing participants two documents which gave detailed step-by-step instructions of how to perform the series of experimental tasks. The first document, the "Pre-Experiment Instructions" (see Appendices A-D) outlined how to download the needed software, how to access saved task files, and how to perform a practice session of the assigned tasks. The second document, "Experiment Instructions" was different for each group as each contained different instructions for the intervention period task (see Appendices E-J).

The software required by the vigilance task is free and was therefore available for participants to download without requiring a license. The instructions pointed to a journal article (Mueller & Piper, 2014), which was also sent to participants. This article referenced the creation of the software for academic/research purposes. This information was provided in order to serve as validation that the software was from a reputable source in case participants had concerns about downloading an unknown software. While downloading the software to one's personal computer was a necessary experimental step, participants did have the option of withdrawing from the study prior to performing this step if they were uncomfortable downloading the software.

Experiment instructions emphasized the need for participants to perform all experiment tasks in one sitting and with any distractions reasonably removed. It is recognized that due to the unsupervised nature of the remote data collection, the experimental settings of the various participants varied much more so than a highly controlled laboratory experiment. Some data screening steps were implemented to filter out non-compliance in experimental instructions. For example, data files included timestamps of when tasks were completed, which could be used to determine the time taken between the pre- and post-intervention period vigilance sessions. If this time greatly exceeded the allotted intervention period time, it was determined that participants did not comply with experimental instructions in regard to task timing, and therefore their data was eliminated from analysis.

Both in recruitment materials as well as experiment instructions, participants were informed that their study compensation was partially dependent on their task

performance. Specifically, participants were told that by participating they could earn up to $15 in gift card value, $10 of which would be guaranteed regardless of performance, while $5 would be dependent on their level of task performance. This performance-based portion of the compensation was used in order to provide extrinsic motivation for task performance.

Performance on the vigilance task was measured in terms of (1) detection rate, (2) response time (RT), and (3) perceptual sensitivity (d') (Green & Swets, 1966). Sensitivity (d'), a common measure of vigilance performance, represents the ability to differentiate between critical signals and non-signals (See et al., 1995). For detection rate and sensitivity (d'), larger values are interpreted as better performance, while for response time, smaller values are better. However, for the sensitivity measure to be able to be calculated, there cannot be a detection rate or false alarm rate of 1 or 0. Since there are often cases when participants have a false alarm rate of 0, and sometimes a detection rate of 1, making their data invalid for sensitivity calculation, this analysis instead made use of a corrected sensitivity measure as described in Hautus (1995).

5.3. Results

Data analysis was performed through R Studio Version 1.2.1335, using an alpha value of 0.05. Graphs were created using Microsoft Excel. Data was divided by the experimental conditions which correspond to the different groups, each of which performed a different task during the intervention period. In addition, data was divided into four periods (Period 0 – 3). Period 0 was the pre-experiment period, during which

only surveys were completed. Period 1 and Period 3 corresponded with the pre- and post-intervention periods, during which all participants performed the vigilance task. Period 2 was the intervention period during which the task performed by the participant depended on their assigned group.

5.3.1. Vigilance Task Performance Measures

Mixed ANOVA was used to allow for comparisons of groups (between-subjects), periods (within-subjects), and their interaction. The analyses were focused on whether there were differences in vigilance task performance between groups from pre-intervention to post-intervention given that the three groups performed different tasks during the intervention period. Significant interaction effects between group and period would indicate that the difference in task performed during the intervention period impacted post-intervention vigilance task performance. Effect sizes are reported in terms of partial eta squared (η_p^2), with the interpretations of the effect sizes being "small" = 0.01, "medium" = 0.06, and "large" = 0.14.

The normality assumption was checked using the Shapiro-Wilk test and visually inspecting Q-Q plots. Homogeneity of variances was assessed using Levene's test. Box's M-test was used to test the homogeneity of covariances assumption. In addition, the particular function of the statistical software used in the analysis automatically applies the Greenhouse-Geisser sphericity correction to within-subject factors violating the sphericity assumption. When results are reported, all assumptions are assumed to be met

or corrected for unless specified otherwise. If assumptions are not met, an alternative analysis is specified.

5.3.1.1. Response Time

For response time, the interaction was significant (p=0.006) with post-hoc tests showing that the mean response time for Group 2 (433 ms) was significantly (p= 0.011) lower than for Group 1 (456 ms) following the intervention period. That is, following the intervention period, the group which rotated to the task of contrasting demands during the intervention period had a significantly lower response time than the group which performed the vigilance task continuously. The post-intervention response time performance of the group which rested was not significantly different from either the continuous vigilance task group or the task rotation group. See Table 5.2 and Figure 5.8 for a summary of these results.

Table 5.2 Statistical results for response time (for Groups 1-3)

Mixed ANOVA for Response Time						
	Sum of Squares	**df**	**Mean Square**	**F**	**p**	η_p^2
Period	94.3	1	94.3	0.454	0.502	0.005
Group	7243.3	2	3621.7	1.498	0.229	0.031
Period x Group	2276.4	2	1138.2	5.479	**0.006**	0.104
Note: Type III Sum of Squares						

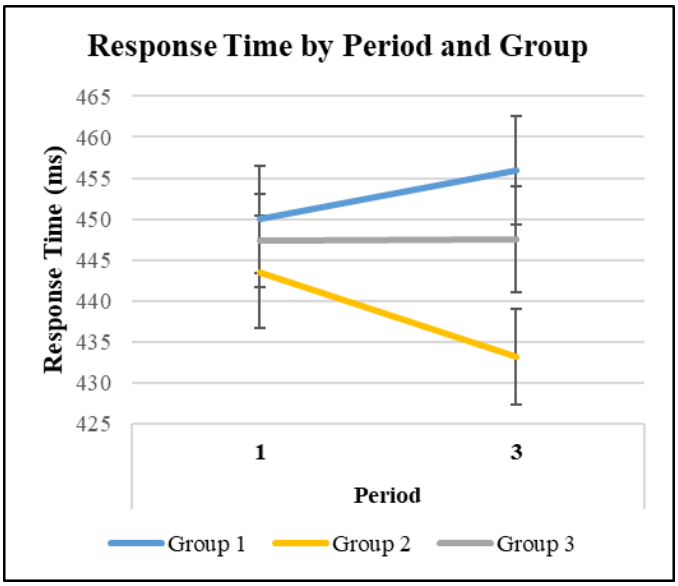

Figure 5.8 Mean values of response time, divided by period and group, with error bars representing standard error of the mean (for Groups 1-3)

5.3.1.2. Detection Rate

For detection rate, the data did not meet the assumption of normality, so it was transformed prior to performing mixed ANOVA. The dependent variable of detection rate was transformed according to the following formula, which is one recommendation from Field et al. (2012).

$$f(x) = \sqrt[2]{\alpha - x}$$

where $\alpha = max\{x_1, \ldots x_N\}$

Following the transformation, the data approximately met the normality assumption.

For the transformed detection rate, the main effect of group (p=0.012) and the interaction (p=0.001) were significant, with post-hoc tests showing that the main effect of group was significant at Block 3, but not Block 1. Pairwise comparisons showed that

the transformed detection rate for Group 2 was significantly different than both Group 1 ($p<0.001$) and Group 3 ($p=0.039$) following the intervention period.

Reverting back to non-transformed detection rate for ease of interpretation, these results show that following the intervention period, the group which rotated to the task of contrasting demands during the intervention period had a significantly higher detection rate than both the group which performed the vigilance task continuously and the group which rested. See Table 5.3 and Figure 5.9 for a summary of these results.

Table 5.3 Statistical results for (transformed) detection rate (for Groups 1-3)

Mixed ANOVA for Detection Rate (Transformed)						
	Sum of Squares	**df**	**Mean Square**	**F**	**p**	η_p^2
Period	0.007	1	0.007	1.462	0.230	0.015
Group	0.442	2	0.221	4.617	**0.012**	0.089
Period x Group	0.072	2	0.036	7.254	**0.001**	0.134
Note: Type III Sum of Squares						

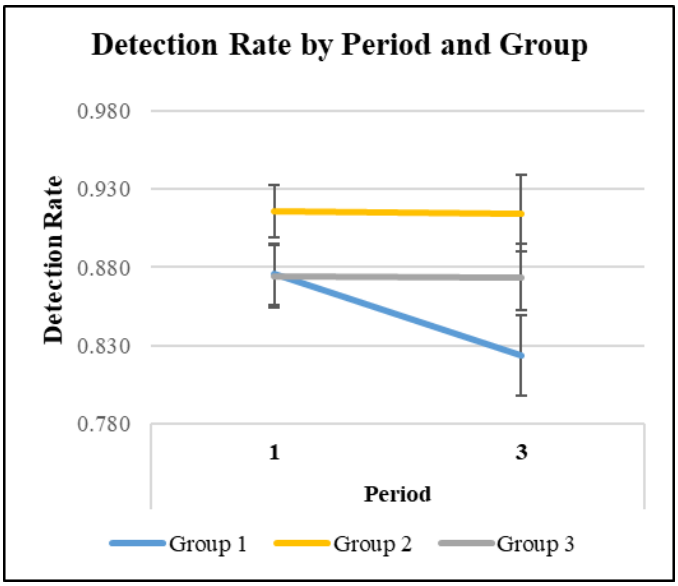

Figure 5.9 Mean values of detection rate (not transformed), divided by period and group, with error bars representing standard error of the mean (for Groups 1-3)

5.3.1.3. Sensitivity

For sensitivity (corrected), the main effect of Group ($p=0.022$) and the interaction ($p<0.001$) were significant, with post-hoc tests showing that the mean sensitivity (corrected) index for Group 2 (4.51) was significantly higher than both Group 1 (3.75) and Group 3 (4.13) post-intervention. That is, following the intervention period, the group which rotated to the task of contrasting demands during the intervention period had a significantly higher mean sensitivity (corrected) index than both the group which performed the vigilance task continuously and the group that rested. See Table 5.4 and Figure 5.10 for a summary of these results.

Table 5.4 Statistical results for sensitivity (corrected) (for Groups 1-3)

Mixed ANOVA for Sensitivity (Corrected)						
	Sum of Squares	**df**	**Mean Square**	**F**	**p**	**η_p^2**
Period	0.066	1	0.066	0.375	0.542	0.004
Group	10.712	2	5.356	3.985	**0.022**	0.078
Period x Group	2.836	2	1.418	8.047	**≤0.001**	0.146
Note: Type III Sum of Squares						

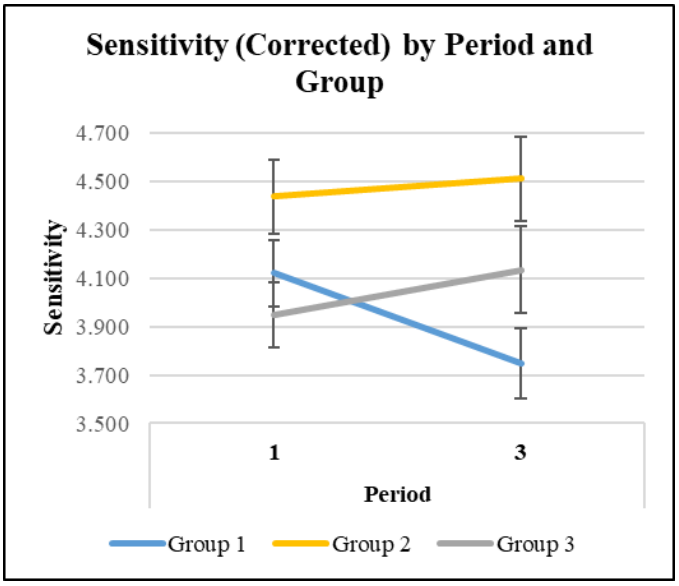

Figure 5.10 Mean values of sensitivity (corrected), divided by period and group, with error bars representing standard error of the mean (for Groups 1-3)

5.3.2. Subjective Measures

Additional analyses were performed on the subjective ratings response data. Again, mixed ANOVA was used to allow for comparisons of groups (between-subjects), periods (within-subjects), and their interaction. The analyses checked whether there were

differences in subjective ratings between groups from pre-intervention to post-intervention given that the three groups performed different tasks during the intervention period. Note that while the analyses for vigilance task performance made the comparisons between Period 1 and Period 3, the subjective ratings comparisons were between Period 0 (before the first vigilance task) and Period 3.

5.3.2.1. Mental Demand

For mental demand, the data did not meet the assumption of normality, so prior to performing mixed ANOVA the dependent variable was transformed according to the following formula.

$$f(x) = \sqrt[2]{\alpha - x}$$

where $\alpha = max\{x_1, \ldots x_N\} + 1$

Following the transformation, the data approximately met the normality assumption.

For the transformed mental demand measure, the main effect of period was significant ($p<0.001$). Looking at the non-transformed data, the mean mental demand across all groups increased from 44.1 in Period 0 to 71.7 in Period 3.

5.3.2.2. Temporal Demand

For temporal demand, the main effect of period was significant ($p=0.002$), with the mean temporal demand measure increasing from 34.1 in Period 0 to 45.0 in Period 3.

5.3.2.3. Performance

For perceived performance, the data did not meet the assumption of normality, so prior to performing mixed ANOVA the dependent variable was transformed according to the following formula.

$$f(x) = \sqrt[2]{x}$$

Following the transformation, the data approximately met the normality assumption.

For the transformed perceived performance measure, the main effect of period was significant (p=0.004). Looking at the non-transformed data, the mean perceived performance score across all groups decreased from 35.6 in Period 0 to 28.3 in Period 3.

5.3.2.4. Effort

For effort, the main effect of period was significant (p<0.001), with the mean effort measure increasing from 49.1 in Period 0 to 64.8 in Period 3.

5.3.2.5. Frustration

For frustration, the main effect of period was significant (p=0.002), with the mean frustration measure increasing from 41.9 in Period 0 to 54.0 in Period 3.

5.3.2.6. Boredom

For boredom, both the main effect of group (p=0.028) and the main effect of period (p<0.001) were significant. Post-hoc tests showed that for Period 3, the mean

boredom level of Group 2 (57.8) was significantly lower (p=0.005) than that of Group 1 (75.2).

5.3.2.7. Mind-Wandering

For mind-wandering, the data did not meet the assumption of normality, so prior to performing mixed ANOVA the dependent variable was transformed according to the following formula.

$$f(x) = \sqrt[2]{\alpha - x}$$

where $\alpha = max\{x_1, \dots x_N\}$

Following the transformation, the data approximately met the normality assumption.

For the transformed mind-wandering measure, the main effect of period was significant (p=0.001). Looking at the non-transformed data, the mean mind-wandering score across all groups increased from 54.1 in Period 0 to 62.1 in Period 3.

5.3.2.8. Other Subjective Measures

For the measures of motivation and physical demand, neither of the main effects nor the interaction were significant.

5.4. Discussion

To answer Question 1, therefore, results from this study indicate that (2) rotating to a task of contrasting cognitive demands will lead to a significantly lesser decrease in vigilance task performance compared to (1) continuous vigilance task performance. In

comparison, the use of a (3) rest break during the intervention period was shown to not result in a significantly lesser decrease in vigilance task performance compared to continuous vigilance task performance. It can therefore be concluded that rotation to the task of contrasting cognitive demands is an effective intervention to the vigilance decrement, arguably even more so than passively resting.

For all the subjective ratings, there were no significant interactions. Multiple subjective measures showed a significant change over time, indicating an effect of tasks performed regardless of the group. The measures of mental demand, temporal demand, effort, frustration, boredom, and mind wandering all increased from Period 0 to Period 3, while perceived performance decreased over this time. In addition, for boredom, the effect of group was also significant for Period 3, with the boredom level of Group 2 (RAT task) being significantly lower than that of Group 1 (continuous vigilance). This significant difference suggests that rotation to the task of contrasting cognitive demands is an effective intervention to the subjective feeling of boredom.

6. EXPERIMENT FOR QUESTIONS 2 – 4

6.1. Hypotheses

Since the task chosen for Group 2 was one which contrasted from the vigilance task in terms of all three dimensions of the MRT model, it was expected that it would be the most effective countermeasure to the vigilance decrement, with the effectiveness of the other rotation tasks, which contrast in terms of only two of three dimensions, falling somewhere in-between the Group 2 task and the rest break intervention.

6.2. Methods

After results showed that the use of rotation to the intervening task (Group 2) led to a significantly lesser decrease in vigilance task performance, a fourth group was added to determine the extent that the effectiveness of the original intervening task was due to the contrast in perceptual modality between the vigilance task and the original intervening task. Group 4, therefore, rotated to a task which differs from the vigilance task only in terms of processing code and predominant processing stage, but not in terms of **perceptual modality** (see Figure 6.2). This allowed for a comparison between Groups 2 and 4 to determine the impact of perceptual modality. The task chosen for Group 4 was a visual form of the RAT. That is, the words were presented visually (see Figure 6.1) rather than auditorily, as they had been for Group 2. Participants recorded their answers by typing them into the same response sheet as was used for the auditory RAT group. As with the auditory RAT, participants did not receive feedback on this

task. Comparison of before and after changes in performance on the vigilance task were made between the groups to determine the specific impact of the **perceptual modality**.

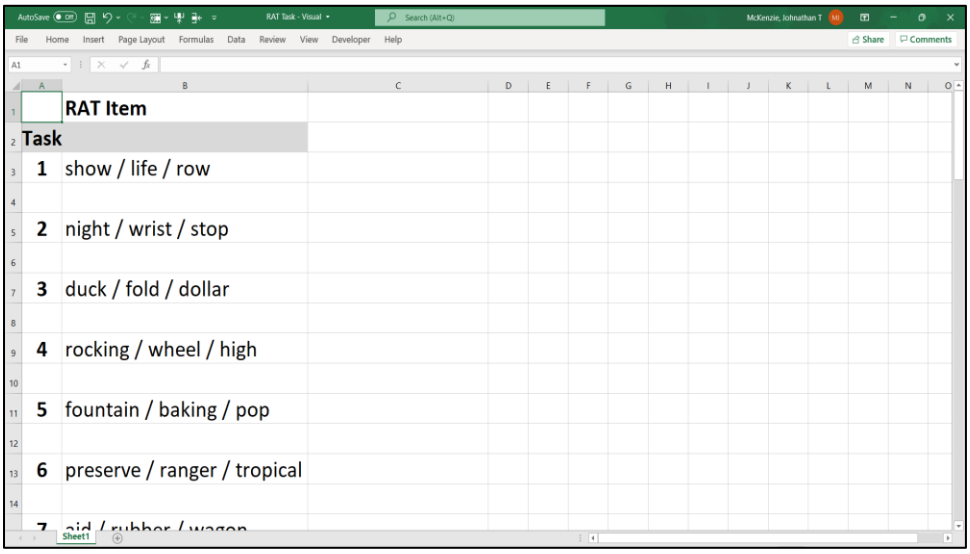

Figure 6.1 Visual remote associates test (RAT) interface

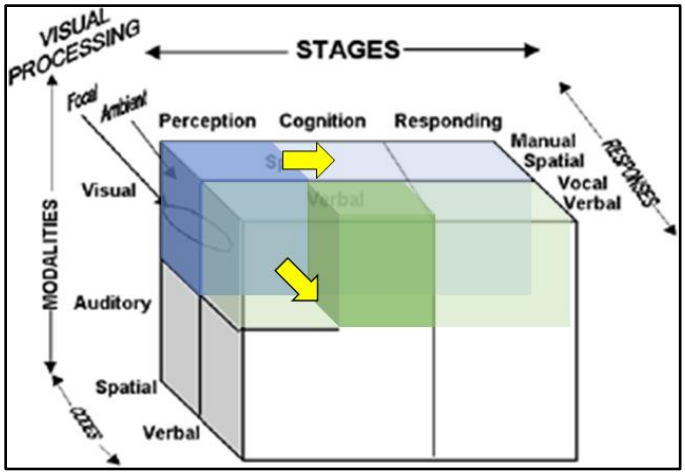

Figure 6.2 Theorized demands of the vigilance task represented by the blue shading and those of the visual RAT task represented by the green shading, with yellow arrows indicating the change of resource dimensions between tasks (adapted from Wickens, 2008)

A fifth group was added to determine the extent that the effectiveness of the original intervening task was due to the contrast in processing code. Group 5, therefore, rotated to a task which differs from the vigilance task only in terms of perceptual modality and predominant processing stage, but not in terms of **processing code** (see Figure 6.4). This allowed for a comparison between Groups 2 and 5 to determine the impact of processing code. The task created for Group 5 is referred to as the multi-adjacent state task (MAST). Participants were auditorily provided with three U.S. state names and then had to think of the fourth state which shares boundaries with each of the three given states. For example, the three given state names could be "New Mexico", "Oklahoma", and "Louisiana", with the correct answer being "Texas". As with the auditory RAT task, although the words were presented auditorily, the interface used to play the sound recordings did require the use of the visual modality and spatial code, as did the typing of responses. Sound files were embedded into a PowerPoint slide (see Figure 6.3) which were played using the same method as was used for the auditory RAT task. Just as with the other intervening tasks, participants did not receive feedback on this task. Comparisons of before and after changes in performance on the vigilance task were made between the groups to determine the specific impact of the **processing code**. Two participants did not provide any answers to the MAST and communicated to the research team that they lacked knowledge of state locations. Therefore, since it was determined that they did not truly perform the MAST (its cognitive demands were not applied), their data was removed prior to analysis.

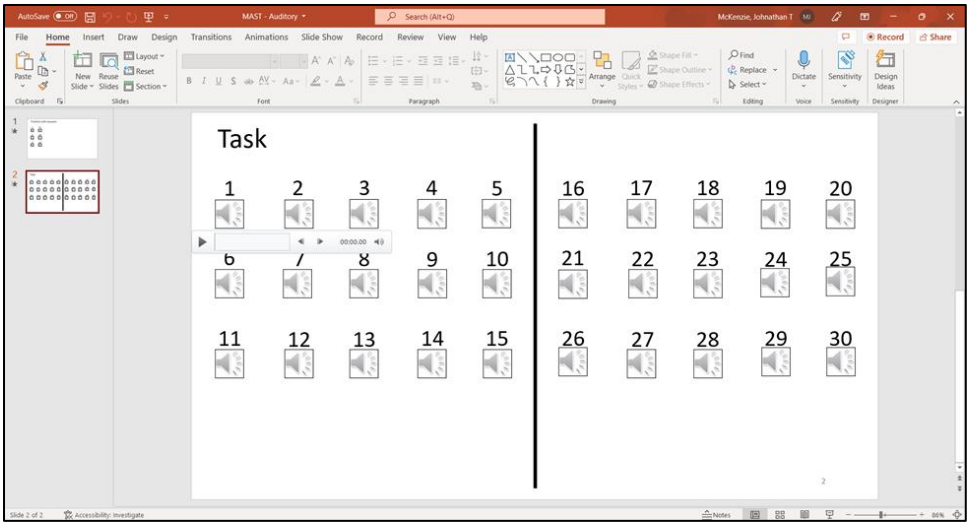

Figure 6.3 Multi-Adjacent State Task (MAST) interface

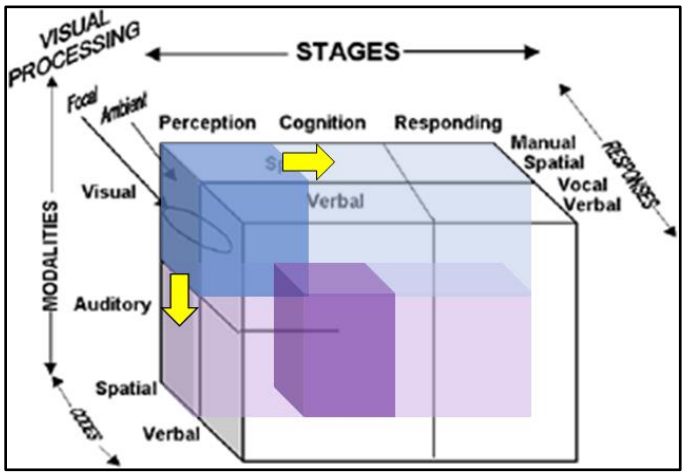

Figure 6.4 Theorized demands of the vigilance task represented by the blue shading and those of the MAST represented by the purple shading, with yellow arrows indicating the change of resource dimensions between tasks (adapted from Wickens, 2008)

A sixth group was added to determine the extent that the effectiveness of the original intervening task was due to the contrast in the predominant processing stage. Group 6, therefore, rotated to a task which differs from the vigilance task only in terms of perceptual modality and processing code, but not in terms of the **predominant**

processing stage (see Figure 6.6). This allowed for a comparison between Groups 2 and 6 to determine the impact of the predominant processing stage. The task created for Group 6 is referred to as the verbal auditory vigilance task (VAVT). To avoid terminology confusion going forward, the phrase "original vigilance task" will be used to refer to the vigilance task performed by all groups in Periods 1 and 3, as well as in Period 2 by Group 1. The acronym VAVT will refer to the intervening task performed by Group 6 in Period 2.

For the VAVT, participants were presented auditorily with a series of tones at a pace similar to that of the original vigilance task. A new tone was presented approximately every one second, with the tone lasting approximately 0.6 seconds, followed by 0.4 seconds of silence. There were two possible tones, tone #1, which was an A4 tone and tone #2 which was an E5 tone. These two specific tones were chosen because they form a harmonic fifth. This means that they are an interval present in "pleasant" sounding tunes (they sound comfortable in-sequence to listeners) (Carcagno et al., 2019). These tones were chosen together therefore to avoid any unnecessary unpleasantness which could impact fatigue in a way not due to the cognitive demands of the task. Participants were instructed to listen to the series of tones and if they detect a repetition of the same tone (e.g., tone #1 – tone #1) then they should respond by pressing the space bar as quickly as possible. If, however, the tones alternate (e.g., tone #1 – tone #2) then they should not respond. This task was designed to be somewhat analogous to the original vigilance task (clock task) in that the repetition of the same tone is essentially a "skip" of one of the alternating tones, with this skip requiring detection.

The probability of a skip for the VAVT was the same as that of the original vigilance task (~0.20). The major difference between the two tasks was the perceptual modality which was required by them (auditory vs visual), as well as the processing code (verbal/symbolic vs spatial). However, although the tones were presented auditorily for the VAVT, the interface used to play the sound recordings did briefly require the use of the visual modality to begin the sound file which played continuously without need of further input. In addition, some participants may have chosen to keep their eyes on the screen (see Figure 6.5) and/or look at the keyboard to help keep their finger properly positioned on the space bar. As with the other intervening tasks, participants did not receive feedback on this task. Comparisons of before and after changes in performance on the original vigilance task were made between the groups to determine the specific impact of the **predominant processing stage**.

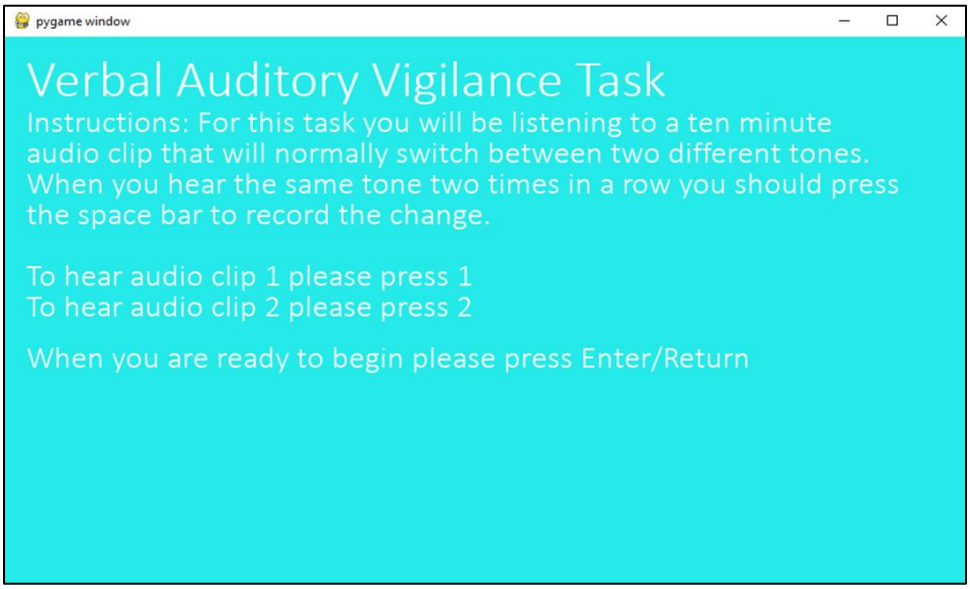

Figure 6.5 VAVT task screen

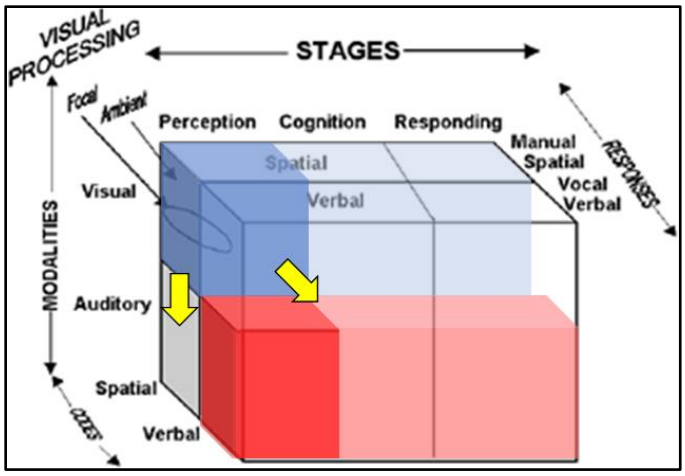

Figure 6.6 Theorized demands of the vigilance task represented by the blue shading and those of the VAVT represented by the red shading, with yellow arrows indicating the change of resource dimensions between tasks (adapted from Wickens, 2008)

The software used for the VAVT was developed by members of the research team in-house. Since a few potential participants had, despite its credibility being vouched for by a published research article, declined to download the software required for the original vigilance task, it was thought that many more potential participants would be resistant to installing the VAVT software which lacked such documentation. Therefore, given this situation and with COVID-19 restrictions lifted at the time, the experiment for Group 6 was conducted in-person at the university research lab. This allowed for the VAVT software as well as the original vigilance software to already be installed on a lab computer rather than a participant's personal computer. Despite being in-person, the experiment was conducted so as to imitate the remote experiment experience as much as possible. Following the consent form process, participants were shown the Word files of the Pre-Experiment Instructions and the Experiment Instructions, both of which were similar to those used by the remote participants. From

this point on, participants followed the document instructions just as remote participants had done. An experimenter did remain in the room in case the participant experienced any problems and/or had any questions.

Just as with Groups 1-3, Groups 4-6 also completed a demographics and work survey as well as two or more subjective ratings surveys. Table 6.1 provides a summary of the series of steps taken by each group. With the addition of Groups 4-6, the total number of participants increased to 191 across the six groups, with each group containing at least 30 participants. Participants in Groups 4 and 5 also completed the study remotely, while Group 6 performed the experiment in-person due to task software complications.

Table 6.1 Experimental steps by group (for Groups 1-6)

	~3 min	~3 min	*survey time (~2 + ~1 min)*		*~10 min + survey time*		*~10 min + survey time*		*~10 min + survey time*	
	Pre-Experiment (Period 0)				**Period 1**		**Period 2**		**Period 3**	
Group 1	clock task practice	intervening task practice	demographics survey	subjective ratings survey	clock task		clock task		clock task	subjective ratings survey
Group 2	clock task practice	intervening task practice	demographics survey	subjective ratings survey	clock task	subjective ratings survey	auditory RAT task	subjective ratings survey	clock task	subjective ratings survey
Group 3	clock task practice	intervening task practice	demographics survey	subjective ratings survey	clock task	subjective ratings survey	rest break		clock task	subjective ratings survey
Group 4	clock task practice	intervening task practice	demographics survey	subjective ratings survey	clock task	subjective ratings survey	visual RAT task	subjective ratings survey	clock task	subjective ratings survey
Group 5	clock task practice	intervening task practice	demographics survey	subjective ratings survey	clock task	subjective ratings survey	MAST	subjective ratings survey	clock task	subjective ratings survey
Group 6	clock task practice	intervening task practice	demographics survey	subjective ratings survey	clock task	subjective ratings survey	VAVT	subjective ratings survey	clock task	subjective ratings survey

6.3. Results

Data was again analyzed through R Studio, using an alpha value of 0.05. As with the previous analysis, data was divided by group and period, with a total of six groups (Group 1 – 6) and four periods (Period 0 – 3). Period 0 was the pre-experiment period, during which only surveys were completed. Period 1 and Period 3 corresponded with the pre- and post-intervention periods, during which all participants performed the vigilance task. Period 2 was the intervention period during which the task performed by the participant depended on their assigned group.

6.3.1. Vigilance Task Performance Measures

Mixed ANOVA was again used to allow for comparisons of groups (between-subjects), periods (within-subjects), and their interaction. The analyses were focused on whether there were differences in vigilance task performance between groups from pre-intervention to post-intervention given that the three groups performed different tasks during the intervention period. Significant interaction effects between group and period would indicate that the difference in task performed during the intervention period impacted post-intervention vigilance task performance. Effect sizes are reported in terms of partial eta squared (η_p^2), with the interpretations of the effect sizes being "small" = 0.01, "medium" = 0.06, and "large" = 0.14.

The normality assumption was checked using the Shapiro-Wilk test and visually inspecting Q-Q plots. Homogeneity of variances was assessed using Levene's test. Box's M-test was used to test the homogeneity of covariances assumption. In addition, the particular function of the statistical software used in the analysis automatically applies the Greenhouse-Geisser sphericity correction to within-subject factors violating the sphericity assumption. When results are reported, all assumptions are assumed to be met or corrected for unless specified otherwise. If assumptions are not met, an alternative analysis is specified.

6.3.1.1. Response Time

For response time, the interaction ($p<0.001$) as well as the main effect of group ($p<0.001$) were significant. Post-hoc tests showed that for both the pre-intervention

period and the post-intervention period, the mean response time for Group 6 was significantly higher than those of Groups 1-5. In addition, just for the post-intervention period, the mean response times for Group 2 (433 ms; p=0.010), Group 4 (430 ms; p=0.004), and Group 5 (428 ms; p= 0.002) were all significantly lower than for Group 1 (456). The mean response time for Group 5 (428 ms) was also significantly lower (p= 0.040) than that of Group 3 (448 ms).

Stated more clearly, the group which performed the VAVT during the intervention period had a significantly higher mean response time than all other groups both pre- and post-intervention period. Following the intervention period, the group which performed the visual RAT, the group which performed the auditory RAT, and the group which performed the MAST all had a significantly lower mean response time than the group which performed the vigilance task continuously. In addition, the group which performed the MAST had a significantly lower post-intervention mean response time than the group which rested during the intervention period. See Table 6.2 and Figure 6.7 for a summary of these results.

Table 6.2 Statistical results for response time (for Groups 1-6)

Mixed ANOVA for Response Time						
	Sum of Squares	**df**	**Mean Square**	**F**	**p**	η_p^2
Period	510.4	1	510.4	2.801	0.096	0.015
Group	74432.7	5	14886.5	6.195	**<0.001**	0.143
Period x Group	4752.6	5	950.5	5.217	**<0.001**	0.124
Note: Type III Sum of Squares						

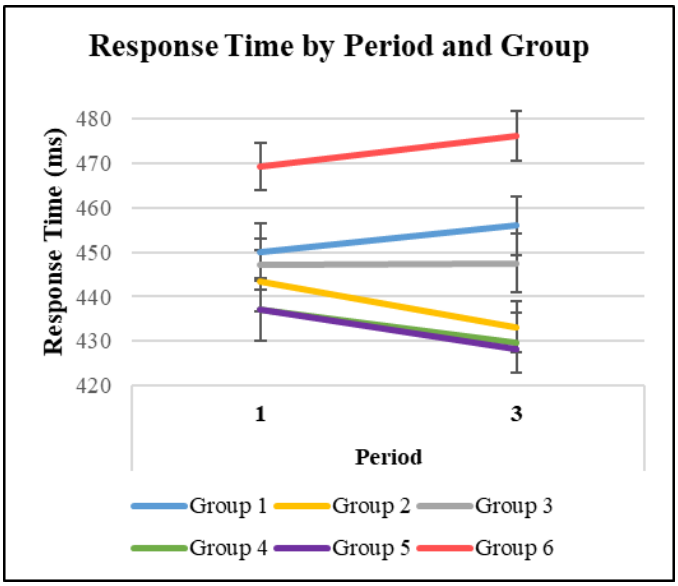

Figure 6.7 Mean values of response time, divided by period and group, with error bars representing standard error of the mean (for Groups 1-6)

6.3.1.2. Detection Rate

For detection rate, the data did not meet the assumption of normality, so it was transformed prior to performing mixed ANOVA. The dependent variable of detection rate was transformed according to the following formula, which is one recommendation from Field et al. (2012).

$$f(x) = \sqrt[2]{\alpha - x}$$

where $\alpha = max\{x_1, \ldots x_N\}$

Following the transformation, the data approximately met the normality assumption.

For the transformed detection rate, the main effect of group ($p<0.001$) and the interaction ($p<0.001$) were significant, with post-hoc tests showing that the main effect of group was significant at both Block 1 ($p=0.015$) and Block 3 ($p<0.001$). Pairwise comparisons showed that for Period 1, the transformed detection rate for both Group 2

and Group 5 were significantly different than both Group 1 and Group 3. In addition, Group 5 was significantly different than Group 6. For Period 3, the transformed detection rate for Groups 2, 4, and 5 were significantly different than both Group 1 and Group 6. In addition, Group 5 was significantly different than Group 3.

Reverting back to non-transformed detection rate for ease of interpretation, these results show that prior to the intervention period, the group which would perform the auditory RAT and the group which would perform the MAST both had mean detection rates which were significantly higher than both the group which that performed the vigilance task continuously and the group that took a rest break. In addition, the group which performed the MAST had a significantly higher mean detection rate than the group which performed the VAVT. Following the intervention period, the group which performed the auditory RAT, the group which performed the visual RAT, and the group which performed the MAST all had significantly higher mean detection rates than the group which performed the vigilance task continuously and the group which performed the VAVT. In addition, the group which performed the MAST had a significantly higher post-intervention mean detection rate than the group which rested. See Table 6.3 and Figure 6.8 for a summary of these results.

Table 6.3 Statistical results for (transformed) detection rate (for Groups 1-6)

Mixed ANOVA for Detection Rate (Transformed)						
	Sum of Squares	**df**	**Mean Square**	**F**	**p**	**η_p^2**
Period	0.002	1	0.002	0.386	0.535	0.002
Group	1.130	5	0.226	4.928	**<0.001**	0.118
Period x Group	0.128	5	0.026	5.301	**<0.001**	0.125
Note: Type III Sum of Squares						

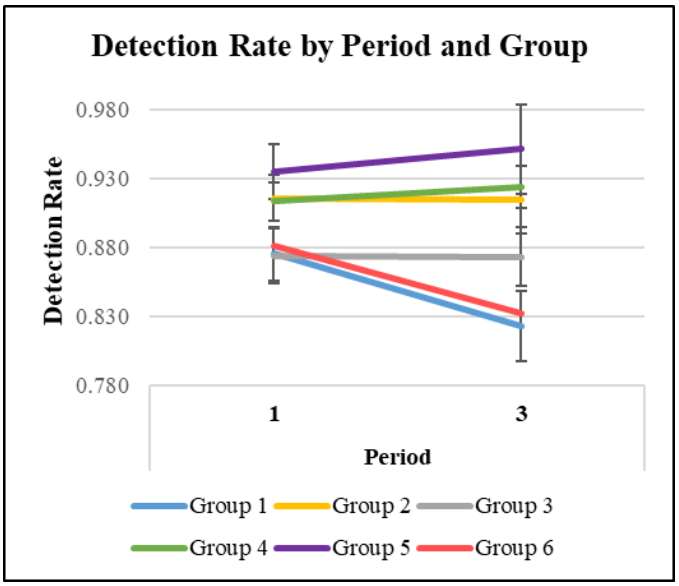

Figure 6.8 Mean values of detection rate divided by period and group, with error bars representing standard error of the mean (for Groups 1-6)

6.3.1.3. Sensitivity

For sensitivity (corrected), the main effect of Group ($p<0.001$) and the interaction ($p=0.001$) were significant. Post-hoc tests showed that for the pre-intervention period the mean sensitivity (corrected) indices of Group 2 (4.43; $p=0.016$), Group 4 (4.44;

p=0.016), and Group 5 (4.64; p<0.001) were all significantly higher than that of Group 3 (3.75). In addition, the pre-intervention mean sensitivity (corrected) index for Group 5 (4.64) was significantly higher (p=0.009) than that of Group 1 (4.12). For the post-intervention period, the mean sensitivity (corrected) indices for Group 2 (4.51; p<0.001), Group 4 (4.52; p<0.001), and Group 5 (4.77; p<0.001) were all significantly higher than that of Group 1 (3.75). In addition, the post-intervention mean sensitivity (corrected) index for Group 5 (4.77) was significantly higher than that of Group 3 (4.13; p=0.007) and Group 6 (4.10; p=0.004).

Stated in terms of tasks performed during the intervention period, the group which performed the visual RAT, the group which performed the auditory RAT, and the group which performed the MAST all had a significantly higher pre-intervention mean sensitivity (corrected) index than the group which rested. The pre-intervention mean sensitivity (corrected) index for the group which performed the MAST was also significantly higher than that of the group which performed the vigilance task continuously. For the post-intervention period, the mean sensitivity (corrected) indices for the group which performed the visual RAT, the group which performed the auditory RAT, and the group which performed the MAST were all significantly higher than that of the group which performed the vigilance task continuously. In addition, the post-intervention mean sensitivity (corrected) index for the group which performed the MAST was significantly higher than for both the group which rested and the group which performed the VAVT. See Table 6.4 and Figure 6.9 for a summary of these results.

Table 6.4 Statistical results for sensitivity (corrected) (for Groups 1-6)

Mixed ANOVA for Sensitivity (Corrected)						
	Sum of Squares	**df**	**Mean Square**	**F**	**p**	**η_p^2**
Period	0.035	1	0.035	0.191	0.663	0.001
Group	27.595	5	5.519	4.376	**<0.001**	0.106
Period x Group	3.882	5	0.776	4.225	**0.001**	0.102
Note: Type III Sum of Squares						

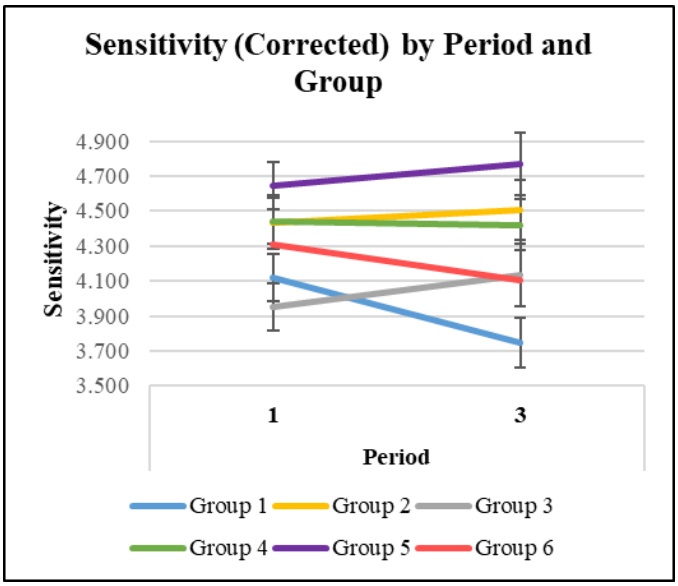

Figure 6.9 Mean values of sensitivity (corrected), divided by period and group, with error bars representing standard error of the mean (for Groups 1-6)

6.3.2. Subjective Measures

Additional analyses were performed on the subjective ratings response data. Again, mixed ANOVA was used to allow for comparisons of groups (between-subjects), periods (within-subjects), and their interaction. The analyses checked whether there was

a difference in subjective ratings between groups from pre-intervention to post-intervention given that the three groups performed different tasks during the intervention period. Note that while the analyses for vigilance task performance made the comparisons between Period 1 and Period 3, the subjective ratings comparisons were between Period 0 (before the first vigilance task) and Period 3.

6.3.2.1. Mental Demand

For mental demand, the data did not meet the assumption of normality, so prior to performing mixed ANOVA the dependent variable was transformed according to the following formula.

$$f(y) = \sqrt[2]{\alpha - y}$$

where $\alpha = max\{y_1 + 1, \dots y_N + 1\}$

where $y = f(x) = \sqrt[2]{\beta - x}$

where $\beta = max\{x_1 + 1, \dots x_N + 1\}$

Following the transformation, the data approximately met the normality assumption.

For the transformed mental demand measure, the main effect of period was significant ($p<0.001$). Looking at the non-transformed data, the mean mental demand across all groups increased from 43.4 in Period 0 to 70.5 in Period 3.

6.3.2.2. Physical Demand

For physical demand, the data did not meet the assumption of normality, so prior to performing mixed ANOVA the dependent variable was transformed according to the following formula.

$$f(x) = \sqrt[2]{x}$$

Following the transformation, the data approximately met the normality assumption.

For the transformed physical demand measure, the main effect of period was significant (p=0.011). Looking at the non-transformed data, the mean physical demand across all groups decreased from 30.0 in Period 0 to 26.6 in Period 3.

6.3.2.3. Temporal Demand

For temporal demand, the main effect of period was significant (p<0.001), with the mean temporal demand measure increasing from 36.6 in Period 0 to 46.3 in Period 3.

6.3.2.4. Performance

For perceived performance, the data did not meet the assumption of normality, so prior to performing mixed ANOVA the dependent variable was transformed according to the following formula.

$$f(x) = \sqrt[2]{x}$$

Following the transformation, the data approximately met the normality assumption.

For the transformed perceived performance measure, the main effect of group (p=0.049) and the main effect of period (p<0.001) were significant. Pairwise

comparisons showed that for Period 3, both Group 4 and Group 5 were significantly different than both Group 1 and Group 6. Looking at the non-transformed data, the post-intervention mean perceived performance score for the group that performed the visual RAT (21.4) and the group that performed the MAST (17.1) were significantly lower than for both the group which performed the vigilance task continuously (32.4) and the group which performed the VAVT (32.5).

6.3.2.5. Effort

For effort, the main effect of period was significant ($p<0.001$), with the mean effort measure increasing from 49.6 in Period 0 to 64.7 in Period 3.

6.3.2.6. Frustration

For frustration, the data did not meet the assumption of normality, so prior to performing mixed ANOVA the dependent variable was transformed according to the following formula.

$$f(y) = \sqrt[2]{\alpha - y}$$

where $\alpha = max\{y_1 + 1, \dots y_N + 1\}$

where $y = f(x) = \sqrt[2]{x}$

Following the transformation, the data approximately met the normality assumption.

For the transformed frustration measure, the main effect of period was significant ($p=0.005$), with the non-transformed mean frustration measure across all groups increasing from 40.7 in Period 0 to 49.2 in Period 3. Pairwise comparisons on the

transformed data showed that post-intervention, Group 4 was significantly different than both Group 1 ($p=0.038$) and Group 3 ($p=0.002$), while Group 5 was significantly different ($p=0.024$) than Group 3. Looking at the non-transformed data, the post-intervention mean frustration score for the group that performed the visual RAT (38.6) was significantly lower than for both the group which performed the vigilance task continuously (53.4) and the group which rested (62.0). In addition, the mean score for the group which performed the MAST (44.6) was significantly lower than for the group which rested (62.0).

6.3.2.7. Boredom

For boredom, the main effect of period was significant ($p<0.001$), with the mean boredom measure increasing from 39.6 in Period 0 to 64.6 in Period 3. Pairwise comparisons showed that the post-intervention mean boredom measure for both Group 2 ($p=0.001$) and Group 5 ($p=0.033$) were significantly lower than for Group 1. That is, the post-intervention mean boredom measure for both the group which performed the auditory RAT (57.8) and the group which performed the MAST (60.2) were significantly lower than for the group which performed the vigilance task continuously (75.2).

6.3.2.8. Motivation

For motivation, the main effect of period was significant ($p<0.001$), with the mean motivation measure increasing from 53.5 in Period 0 to 61.5 in Period 3.

6.3.2.9. Mind-Wandering

For mind-wandering, the data did not meet the assumption of normality, so prior to performing mixed ANOVA the dependent variable was transformed according to the following formula.

$$f(y) = \sqrt[2]{\alpha - y}$$

where $\alpha = max\{y_1 + 1, \ldots y_N + 1\}$

where $y = f(x) = \sqrt[2]{x}$

Following the transformation, the data approximately met the normality assumption.

For the transformed mind-wandering measure, the main effect of period was significant (p=0.010), with the non-transformed mean mind-wandering measure across all groups increasing from 54.4 in Period 0 to 59.9 in Period 3. Pairwise comparisons on the transformed data showed that post-intervention, Group 4 was significantly different (p=0.019) than Group 1. Looking at the non-transformed data, the post-intervention mean mind-wandering score for the group which performed the visual RAT (50.9) was significantly lower than for the group which performed the vigilance task continuously (67.4).

6.3.3. Intervening Task Measures

While changes in performance on the vigilance task were the main interest to this research, analyses of performance on the different intervening tasks were also completed. During the intervention period (Period 2), Group 2 performed an auditory version of remote associates test (RAT) task, Group 4 performed a visual version of the

RAT task, and Group 5 performed the multi-adjacent state task (MAST). Performance on each of these tasks were measured by (1) number of questions attempted ("number attempted") and (2) number of questions correctly answered ("number correct"). Each of the groups performed their respective task for approximately 10 minutes and were provided with 30 questions which they could attempt to answer. These shared performance measures and task characteristics allowed for the comparison of performance across groups.

For number attempted, the data did not meet the assumption of normality, so prior to performing one-way ANOVA the dependent variable was transformed according to the following formula.

$$f(x) = \sqrt[2]{\alpha - x}$$

where $\alpha = max\{x_1 + 1, \ldots x_N + 1\}$

Following the transformation, the data still did not completely meet the normality assumption.

For the transformed number attempted measure, the effect of group was significant (p=0.017), with the mean measure of Group 2 being significantly different than both Group 4 (p=0.039) and Group 5 (p=0.033). In terms of the non-transformed data, the mean number attempted for the group which performed the auditory RAT (21.5) was less than that of both the group which performed the visual RAT (24.9) and the group which performed the MAST (24.8). See Table 6.5 and Figure 6.10 for a summary of these results.

Table 6.5 Statistical results for (transformed) number attempted

One-Way ANOVA for Number Attempted (Transformed)						
	Sum of Squares	**df**	**Mean Square**	**F**	**p**	η_p^2
Group	9.05	2	4.525	4.246	**0.017**	0.09
Note: Type II Sum of Squares						

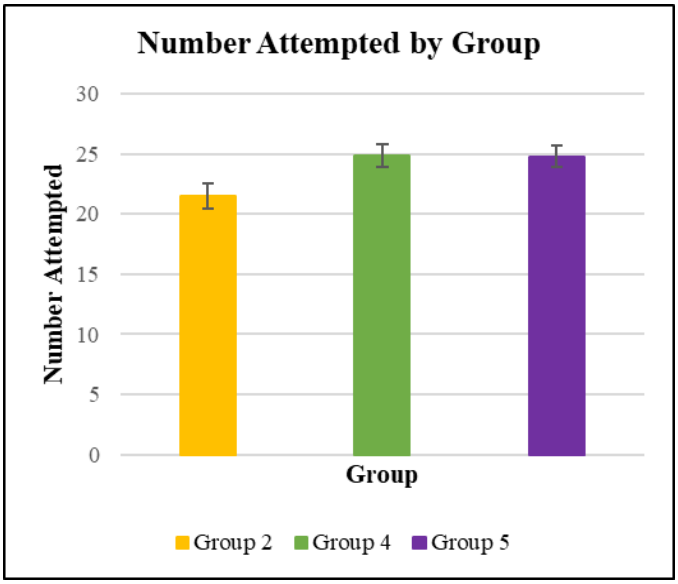

Figure 6.10 Mean number of intervening task questions attempted, divided by group, with error bars representing standard error of the mean

For number correct, the effect of group was significant (p=0.030), with the mean number correct for Group 2 (15.3) being significantly lower (p=0.024) than that of Group 4 (20). There was not a significant difference between Group 5 and the other two groups. Stated in terms of task performed, the group which performed the auditory RAT had significantly lower number of correct answers than the group which performed the visual RAT. And the number correct for the group which performed the MAST was not

significantly different than the other two groups. See Table 6.6 and Figure 6.11 for a summary of these results.

Table 6.6 Statistical results for number of correct answers

One-Way ANOVA for Number Correct						
	Sum of Squares	**df**	**Mean Square**	**F**	**p**	η_p^2
Group	357.06	2	178.53	3.635	**0.030**	0.075
Note: Type II Sum of Squares						

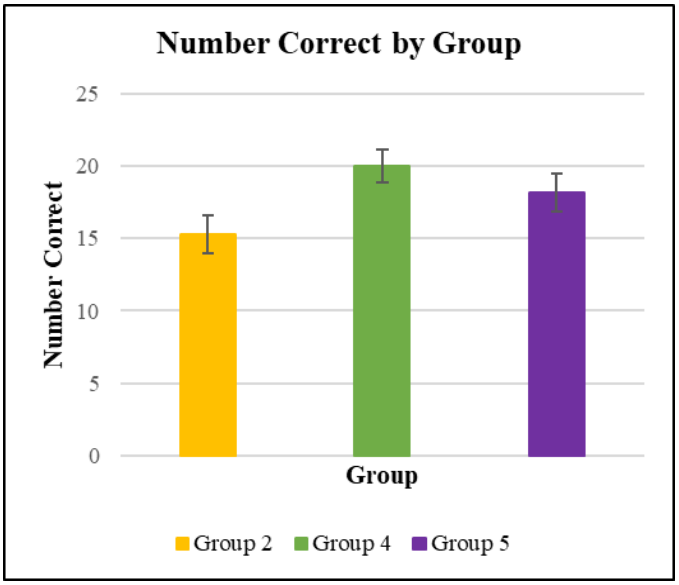

Figure 6.11 Mean values of number of correct answers, divided by group, with error bars representing standard error of the mean

Group 6 performed the verbal auditory vigilance task (VAVT), which has performance measures which differ from those of the other three intervening tasks but are similar to those of the original vigilance task. Therefore, performance comparisons

were made between the VAVT and the original vigilance task. And since Group 1 was the only group which performed the original vigilance task during Period 2 (during which Group 6 performed the VAVT) performance differences between these two groups on their respective tasks were analyzed for this period.

For detection rate, the assumption of normality was not met, so the Kruskal-Wallis test was performed on the data. Results showed that the mean detection rate for Group 1 (0.82) was significantly higher ($p=0.030$) than that of Group 6 (0.75). For response time, the homogeneity of variance assumption was not met, so the Welch one-way ANOVA test was performed. There was not a significant difference between the two groups in terms of response time ($p=0.223$). For sensitivity (corrected), the Kruskal-Wallis test was performed due to the failed normality assumption. The mean sensitivity (corrected) index for Group 1 (3.76) was significantly higher ($p=0.005$) than that of Group 6 (3.06). In terms of task performed, the group which performed the original vigilance task had a significantly higher detection rate and sensitivity (corrected) index than did the group which performed the VAVT.

Subjective measures were also compared between all four groups which performed an intervening task during Period 2. The between-group comparisons were made for the ratings taken at the end of Period 2 (intervention period). For all the measures, the normality assumption was not met, so the Kruskal-Wallis test was performed. For mental demand, temporal demand, and effort, there was no significant difference between the groups. However, for physical demand, perceived performance, frustration, boredom, motivation, and mind-wandering, there was a significant

difference between the groups. The mean physical demand for Group 6 (20.4) was significantly higher than for both Group 4 (7.93; $p=0.001$) and Group 5 (12.7; $p=0.044$). The mean perceived performance measure for Group 4 (33.7) was significantly lower than both Group 2 (48.5; $p=0.026$) and Group 5 (52.6; $p=0.006$). The mean frustration measure for Group 4 (36.9) was significantly lower than that of Group 2 (53.4; $p=0.034$), Group 5 (54.1; $p=0.026$), and Group 6 (57.3; $p=0.004$). The mean boredom measure for Group 6 (58.1) was significantly higher than for Group 2 (20.3; $p<0.001$), Group 4 (15.9; $p<0.001$), and Group 5 (15.4; $p<0.001$). The mean motivation measure for Group 6 (59.4) was significantly lower than for Group 2 (74.6; $p=0.028$), Group 4 (84.1; $p<0.001$), and Group 5 (71.9; $p=0.036$). In addition, the mean motivation measure for Group 4 was significantly higher than for both Group 2 ($p=0.026$) and Group 5 ($p=0.026$). The mean mind-wandering measure for Group 6 (61.0) was significantly higher than for Group 2 (24.3; $p<0.001$), Group 4 (26.6; $p<0.001$), and Group 5 (20.1; $p<0.001$).

In terms of intervening task performed, the group which performed the VAVT had significantly higher levels of boredom and mind-wandering and significantly lower motivation than all other intervening-task groups. In addition, the group which performed the VAVT had a significantly higher physical demand than the group which performed the visual RAT and the group which performed the MAST. The group which performed the visual RAT had significantly lower perceived performance, but significantly higher motivation than both the group which performed the auditory RAT

and the group which performed the MAST. In addition, the group which performed the visual RAT also had a significantly lower level of frustration than all other groups.

6.3.4. Analysis of Intervening Tasks

It was proposed that the intervening task should be one which: (1) places cognitive resource demands on the human which are different than those of the vigilance task, (2) leads to an increase in arousal when performed, (3) naturally draws attention to itself and/or is intrinsically rewarding, and therefore (4) does not require as much top-down attentional control (self-regulation), and hence (5) requires much less effort. The different intervening tasks were chosen primarily to meet the requirement of (1). However, it is less clear whether these tasks met characteristics (2) and (3). Physiological measures, which could be used to infer changes in arousal were not collected during this experiment. Therefore, changes in particular subjective measures were analyzed to infer changes in arousal from Period 1 (when the original vigilance task was performed) to Period 2 (when the different intervening tasks were performed). The collected measures assumed to be related to arousal are boredom and motivation. And similarly, to determine if the different intervening tasks met the characteristics of (3), changes in particular subjective measures were again analyzed. The collected measures of boredom, motivation, and mind-wandering are assumed to be indicative of the intrinsically rewarding nature of each of the intervening tasks.

6.3.4.1. Boredom

For boredom, the data did not meet the assumption of normality, so prior to performing repeated measures ANOVA the dependent variable was transformed according to the following formula.

$$f(y) = \sqrt[2]{\alpha - y}$$

where $\alpha = max\{y_1 + 1, \dots y_N + 1\}$

where $y = f(x) = \sqrt[2]{x}$

Following the transformation, the data approximately met the normality assumption.

The mean transformed boredom measure was significantly different at Period 1 and Period 2 across all groups. Post-hoc tests showed that for Groups 2, 4, and 5, there was a significant change in the mean transformed boredom measure ($p<0.001$). Looking at the non-transformed data for each of these groups, the mean boredom measure decreased from Period 1 to Period 2. For Group 6, however, the mean boredom measure slightly increased (not a significant change).

6.3.4.2. Motivation

For motivation, the data did not meet the assumption of normality, so prior to performing repeated measures ANOVA the dependent variable was transformed according to the following formula.

$$f(x) = \sqrt[2]{\alpha - x}$$

where $\alpha = max\{x_1 + 1, \dots x_N + 1\}$

Following the transformation, the data approximately met the normality assumption. The mean transformed motivation measure was significantly different at Period 1 and Period 2 across all groups. Post-hoc tests showed that for Groups 2, 4, and 5, there was a significant change in the mean transformed motivation measure. Looking at the non-transformed data for each of these groups, the mean motivation measure increased from Period 1 to Period 2. For Group 6, however, the mean motivation measure slightly decreased (not a significant change).

6.3.4.3. Mind-Wandering

For mind-wandering, the data did not meet the assumption of normality, so prior to performing repeated measures ANOVA the dependent variable was transformed according to the following formula.

$$f(y) = \sqrt[2]{\alpha - y}$$

$$\text{where } \alpha = max\{y_1 + 1, \dots y_N + 1\}$$

$$\text{where } y = f(x) = \sqrt[2]{x}$$

Following the transformation, the data approximately met the normality assumption.

The mean transformed mind-wandering measure was significantly different at Period 1 and Period 2 across all groups. Post-hoc tests showed that for Groups 2, 4, and 5, there was a significant change in the mean transformed mind-wandering measure. Looking at the non-transformed data for each of these groups, the mean mind-wandering measure decreased from Period 1 to Period 2. For Group 6, however, the mean mind-wandering measure slightly increased (not a significant change).

6.4. Discussion

To answer Question 2 (concerning the extent of the impact of **perceptual modality**), the comparison of pre- to post-intervention vigilance task performance between Group 2 and Group 4 must be considered. In terms of response time, detection rate, and sensitivity, both Group 2 and Group 4 outperformed Group 1 in post-intervention performance, with the performance of Group 2 and Group 4 not being significantly different. Therefore, despite the Group 4 intervening task not contrasting from the vigilance task in terms of perceptual modality, but only in terms of processing code and predominant processing stage, it was still as effective in lessening the vigilance decrement as Group 2 which contrasted in terms of all three dimensions. Thus, it can be concluded that the effectiveness of the original task rotation was *insignificantly* impacted by the contrast of perceptual modality.

To answer Question 3 (concerning the extent of the impact of **processing code** modality), the comparison of pre- to post-intervention vigilance task performance between Group 2 and Group 5 must be considered. In terms of response time, detection rate, and sensitivity, both groups significantly outperformed Group 1 in post-intervention performance, with the performance of Group 2 and Group 5 not being significantly different. For response time, Group 5 also outperformed Group 3. For sensitivity, however, Group 5 also outperformed Group 1 pre-intervention, complicating the interpretation of its outperformance post-intervention. Group 2 pre-intervention sensitivity performance was not significantly different from Group 1, allowing the superior post-intervention performance to be attributed only to the difference in task

performed during the intervention period rather than pre-existing differences in group performance, which must be at least partially responsible for the superior post-intervention performance of Group 5 over Group 1.

It is therefore indeterminant from the current analysis whether pre-to-post intervention changes in vigilance task performance were superior for Group 2 or Group 5. However, since there was not a significant difference in pre- or post-intervention vigilance task performance between Group 2 and Group 5, it can be argued that the impacts of both intervening tasks on vigilance task performance were statistically the same. If this interpretation is correct, then despite the Group 5 intervening task not contrasting from the vigilance task in terms of processing code, but only in terms of perceptual modality and predominant processing stage, it was still as effective in lessening the vigilance decrement as Group 2 which contrasted in terms of all three dimensions. Thus, it can be concluded that the effectiveness of the original task rotation was *insignificantly* impacted by the contrast in terms of processing code.

To answer Question 4 (concerning the extent of the impact of **predominant processing stage**), the comparison of pre- to post-intervention vigilance task performance between Group 2 and Group 6 must be considered. In terms of response time, all groups performed better than Group 6 both pre- and post-intervention, complicating the interpretations of group comparisons involving Group 6. In terms of detection rate, Group 2 had significantly better post-intervention performance than both Group 1 and Group 6. The performance of Group 2 was also better than Group 1 pre-intervention, adding some complication to the interpretation. But given that Group 2

outperformed Group 6 post-intervention, it can be concluded that the intervening task performed by Group 2 was more effective than that of Group 6 in terms of detection rate. For sensitivity, Group 2 had significantly better post-intervention performance than did Group 1, while there was no significant difference between Group 6 and Group 1. Overall, therefore, the task performed by Group 6 was not nearly as effective at lessening the vigilance decrement as was the task performed by Group 2. Thus, since the intervening task performed by Group 6, which contrasted from the original vigilance tasks in terms of perceptual modality and processing code, but not predominant processing stage was not as effective in lessening the vigilance decrement as Group 2, which contrasted in terms of all three dimensions, it can be concluded that the effectiveness of the original task rotation was *significantly* impacted by the contrast in predominant processing stage.

For all subjective measures there were no significant interactions. Multiple subjective measures showed a significant change over time, indicating an effect of tasks performed regardless of the group. From pre- to post-intervention period, the measures of mental demand, temporal demand, effort, frustration, boredom, motivation, and mind-wandering significantly increased across all groups, while the measures of physical demand and perceived performance decreased across all groups. The change in most of these measures follows expectations, with the exception of motivation which saw an increase over time despite an expected decrease.

Pairwise comparisons did reveal some significant post-intervention differences between groups. In terms of perceived performance, against expectations both Group 4

and Group 5 had a lower mean perceived performance than did Group 1 and 6. This perception of performance contrasts with actual performance, which in general, was better for Groups 4 and 5 than for Groups 1 and 6. The mean post-intervention frustration measure for Group 4 was significantly less than that of both Group 1 and Group 3. In addition, the mean frustration level of Group 5 was significantly lower than that of Group 3. Finally, the mean post-intervention boredom measures for both Group 2 and Group 5 were significantly lower than that of Group 1.

Intervention period comparisons of performance and subjective measures between the four intervening-task groups provide additional insight when interpreting the relative impact that each of the intervening tasks had on pre-to-post vigilance task performance. Three groups (Groups 2, 4, & 5) performed an intervening task which contrasted the original vigilance task in terms of predominant processing stage and made use of similar performance measures allowing for their comparison. The group which performed the auditory RAT appeared to have more difficulty with their task than did the other two groups, as indicated by their relative performance measures. When compared to the performance of the group performing the original vigilance task during the same period, performance on the VAVT indicated that it was more difficult than the original vigilance task. Subjective measures indicated that performing the VAVT led to higher levels of boredom and mind-wandering and lower motivation than did performing the other intervening tasks. In addition, the VAVT appears to have made a higher physical demand than most of the other intervening tasks. The visual RAT appears to have led to a lower level of frustration than did all the other intervening tasks.

An analysis was performed to infer whether each of the intervening tasks met the desired qualities of increasing energetic arousal and being intrinsically rewarding. In comparison to performing the original vigilance task (during Period 1) the intervening tasks performed by Groups 2, 4, and 5 during the intervention period all led to significant decreases in boredom and mind-wandering, as well as significant increases in motivation. However, there were no significant changes in these measures for Group 6. The change in these measures for Groups 2, 4, and 5 can possibly imply that the intervening tasks performed by these groups did indeed lead to an increase in energetic arousal and were perceived as more intrinsically rewarding in comparison to the original vigilance task.

7. EXPERIMENT FOR QUESTION 5

7.1. Hypotheses

At the time when this experiment was being designed, only the results from the experiment for Question 1 had been analyzed, which led to hypotheses for this experiment only being informed by these results and not the results for Questions 2-4. Being informed by the results for Question 1 therefore, it was hypothesized that a task of contrasting cognitive demands (in terms of all three dimensions) could be used effectively as a countermeasure to the cognitive fatigue experienced within the context of the driving environment.

7.2. Methods

The final study was designed to investigate the effectiveness of task rotation as a countermeasure to driving-induced cognitive fatigue within a semiautonomous vehicle setting. A scenario was developed in a STISIM simulator which sought to mimic a highway driving environment – the kind typically experienced by both long-haul truck drivers and drivers in their personal vehicles.

The vehicle in the driving task was semi-automated in that after a brief warm-up distance of approximately one mile, the automated gas/break turned on which fixed the speed of the vehicle to be 60 miles per hour. Participants were still responsible for maintaining the vehicle's lane position. In addition, as a secondary task, participants had to perform a vigilance-type signal monitoring task. As shown in Figure 7.1, a white box

with a green line was visible on the dashboard of the vehicle. Participants were told that these symbols were designed to imitate a sensor display system which must be monitored for errors. When the system was functioning properly, the green line would move clockwise sequentially around each of the four sides of the white box, representative of the four sides of the vehicle. As long as the sensor display system functioned properly, it required no input from the driver. However, when an error occurred, an indicated by a skipped side, the driver was instructed to respond by pressing the brake pedal as quickly as possible. This action did not impact the vehicle's dynamics since the speed was fixed by the vehicle's automation. The brake pedal had to be used as the response method rather than response buttons located on the steering wheel due to data recording problems with steering wheel buttons.

The green line completed a full movement approximately every second, being present for approximately 0.6 seconds and then being absent for approximately 0.4 seconds before reappearing in the next position. This timing was designed so as to imitate the timing of the original vigilance task used in the basic experiment.

Driving task performance was measured in terms of response distance to skips, detection rate of skips, and average lane deviation. Due to the design of the data collection for the skip detection task, it was infeasible to determine false alarm rate and therefore the measure of sensitivity was not calculated.

Figure 7.1 Screen for semi-automated driving simulator task

As with the prior experiments, the experiment time was divided into three main periods (Periods 1-3), with Period 2 being the intervention period during which different groups performed different tasks. Each of the periods lasted approximately 10 minutes, making the total task time across all three periods be approximately 30 minutes. Group 1 performed the driving task continuously for all three periods. Groups 2 and 3 both performed the driving task in Periods 1 and 3, but in Period 2, Group 2 rotated to performing the intervening task, while Group 3 took a rest break. The intervening task used is one which is "different" in terms of the key contrasting demand(s) identified in the prior studies, while also seeking to be more applied than was the auditory RAT task used in the first experiment.

While still heavily remaining in the experimental-based realm, the choice of an intervening task which is close to real-world task will promote further exploration into

the adoption of the task rotation countermeasure into actual industry. The intervening task chosen is one which contrasts the vigilance demands of driving in terms of (a) perceptual modality, (b) processing code, and (c) predominant processing stage. That is, it is a task which primarily makes use of the auditory modality, the verbal code, and the cognition stage.

The intervening task is referred to as the "New Aggie Information Helpline Task". Participants remained seated in the driving simulator and put on headphones in order to listen to a series of audio recordings designed to imitate phone calls made by hypothetical new students at Texas A&M University. A requirement for participation in the study (as stated in recruitment materials) was to either be a student and/or have a general familiarity with the experience of being at student at Texas A&M. To eliminate the necessity of navigating sound files on a computer (which would have required visual and spatial processing), participants simply spoke their sound navigation instructions to the experimenter who then operated the computer to play the appropriate sound files. Example commands included "repeat", "skip", and "next". The full list of questions is included in Appendix P. Questions were chosen so as to elicit generative responses from participants. For example, one question stated, "Are there any classes you recommend I try to take even if they aren't part of my major?" Again, to avoid the requirement of spatial processing, questions related to campus directions or other navigation tasks were avoided. After listening to a question, participants were instructed to speak free-flow and to just restart if they made a mistake. Verbal responses from participants were recorded continuously along with the audio of the sound files played to allow for the "scoring" of

responses following the completion of the task. Performance on this task was measured in terms of (1) number of questions attempted and (2) average score (1-3 range) on the quality of responses (subjectively graded). To create an immersive environment, the driving simulator screen was replaced by a graphic representative of the task (see Figure 7.2), and as with the driving task, the experimenter remained separated from the participant by a screen.

Figure 7.2 Screen background for New Aggie Information Helpline task

Again, this current research work acknowledges, but does not address the feasibility issues of real-world task rotation within the current organizational practices of companies such as the long-haul trucking industry. However, while many helpline operator jobs likely fall outside of the trucking industry, a review of job postings of some major long-haul trucking companies revealed positions within the company which do appear to meet our theoretical requirements. For example, the position of

"Breakdown Coordinator" requires "...answering incoming breakdown calls and resolving equipment issues…" and "...[making] safe, cost-effective decisions…". And the position of "Driver Recruiter" involves "...[engaging] driver leads through inbound and outbound calls sourced by our internal advertising teams…" (J. B. Hunt, 2021).

Thirty-one participants took part in this study, divided across the three groups, with each group containing at least ten participants. The number of participants included in the study was limited by time, lab availability constraints, and recruitment constraints.

In addition to collecting driving task performance data, subjective ratings of fatigue-related measures were taken at various points, similar to the prior experiments. Again, recorded responses included the measures of mental demand, physical demand, temporal demand, perceived performance, effort, frustration, boredom, motivation, and amount of mind-wandering. Participants were handed a laptop to complete the surveys while remaining seated in the driving simulator.

By having this experiment take place entirely in-person, it allowed for the collection of physiological data. Participants were fitted with an Actiheart 5 device, which collected heart rate data and a Pupil Core eye tracking headset. Heart rate data was collected for the entire experiment, but due to file size limitations, eye tracking data was only collected for the first five minutes of the Period 1 driving task and the last five minutes of the Period 3 driving task.

7.3. Results

Data analysis was performed through R Studio Version 1.2.1335, using an alpha value of 0.05. Graphs were created using Microsoft Excel. Data was divided by the experimental conditions which correspond to the different groups, each of which performed a different task during the intervention period. In addition, data was divided into four periods (Period 0 – 3). Period 0 was the pre-experiment period, during which only surveys were completed. Period 1 and Period 3 corresponded with the pre- and post-intervening task periods, during which all participants performed the driving task. Period 2 was the intervention period during which the task performed by the participant depended on their assigned group. Effect sizes are reported in terms of partial eta squared (η_p^2), with the interpretations of the effect sizes being "small" = 0.01, "medium" = 0.06, and "large" = 0.14.

7.3.1. Driving Task Performance Measures

Mixed ANOVA was used to allow for comparisons of groups (between-subjects), periods (within-subjects), and their interaction. The analyses were focused on whether there was a difference in driving task performance between groups from pre-intervention to post-intervention given that the three groups performed different tasks during the intervention period. Significant interaction effects between group and period would indicate that the difference in task performed during the intervention period impacted post-intervention vigilance task performance.

7.3.1.1. Response Distance

For response distance, neither of the two main effects nor the interaction were significant. However, pairwise comparisons showed that for the post-intervention period, the mean response distance for Group 2 (55.9 feet) was significantly lower (p=0.041) than that of Group 1 (61.9 feet). No significant differences were shown to exist between Group 3 and the other two groups.

Stated in terms of tasks performed during the intervention period, the group which performed the New Aggie Information Helpline Task had a significantly lower post-intervention mean response distance than the group which performed the driving task continuously. There was no significant difference in mean response distance between the group which rested and the other two groups. See Table 7.1 and Figure 7.3 for a summary of these results.

Table 7.1 Statistical results for response distance (for driving task)

Mixed ANOVA for Response Distance						
	Sum of Squares	**df**	**Mean Square**	**F**	**p**	η_p^2
Period	11.695	1	11.695	1.804	0.190	0.061
Group	223.648	2	111.842	1.760	0.190	0.112
Period x Group	29.523	2	14.762	2.277	0.121	0.140
Note: Type III Sum of Squares						

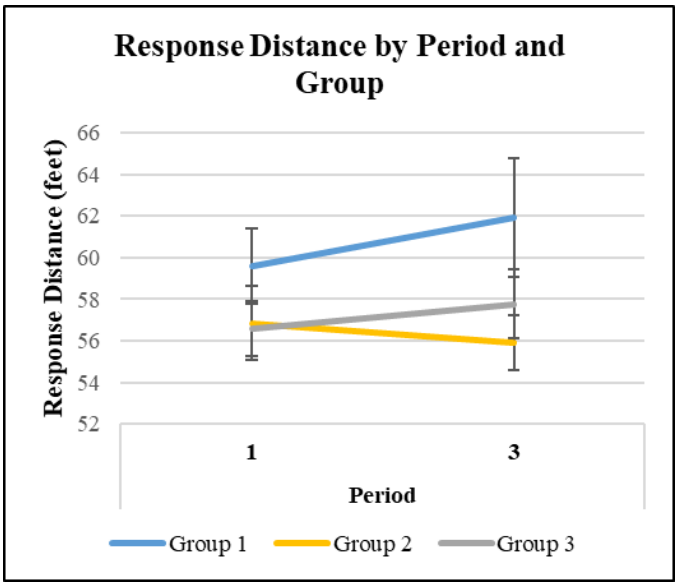

Figure 7.3 Mean values of response distance, divided by period and group, with error bars representing standard error of the mean (for driving task)

7.3.1.2. Detection Rate

For detection rate, the interaction ($p=0.003$) and the main effect of group ($p<0.001$) were both significant. Post-hoc tests showed that for the pre-intervention period, the mean detection rates of both Group 2 ($p=0.005$) and Group 3 ($p=0.002$) were significantly higher than that of Group 1. In addition, for the post-intervention period, the mean detection rates of both Group 2 ($p<0.001$) and Group 3 ($p<0.001$) were again significantly higher than that of Group 1. There were no significant differences between the mean detection rates of Group 2 and Group 3 at either period. The assumption of homogeneity of covariances for this analysis was not met.

Stated in terms of tasks performed during the intervention period, the group which performed the New Aggie Information Helpline task and the group which rested, both had a significantly higher pre- and post-intervention mean detection rate than the

group which performed the driving task continuously. There was not a significant difference in mean detection rate performance between the helpline task group and the rest break group either before or after the intervention period. See Table 7.2 and Figure 7.4 for a summary of these results.

Table 7.2 Statistical results for detection rate (for driving task)

Mixed ANOVA for Detection Rate						
	Sum of Squares	**df**	**Mean Square**	**F**	**p**	η_p^2
Period	0.005	1	0.005	1.883	0.181	0.063
Group	0.923	2	0.462	9.836	**<0.001**	0.413
Period x Group	0.041	2	0.021	8.221	**0.002**	0.370
Note: Type III Sum of Squares						

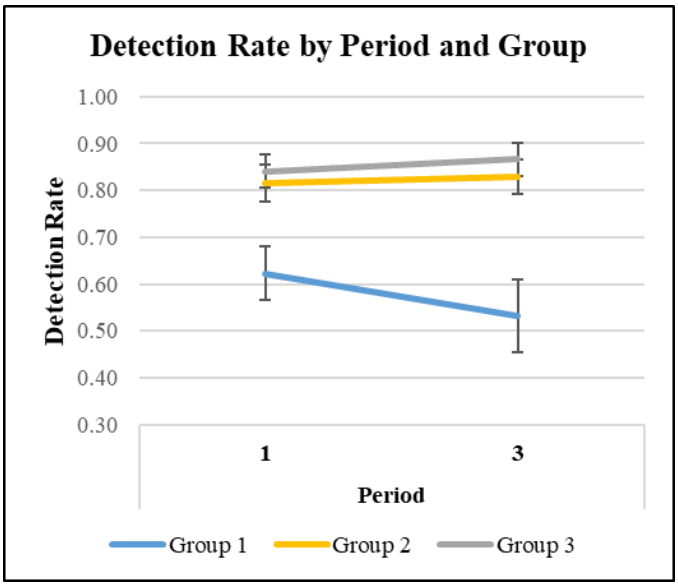

Figure 7.4 Mean values of detection rate, divided by period and group, with error bars representing standard error of the mean (for driving task)

While the interaction was significant, since the main effect of group was also significant, it could not be determined from post-hoc tests whether or not the mean detection rate of Group 2 and Group 3 being significantly higher was due to the different task performed during the intervention period. To make this determination, an additional test was performed on a new variable, detection rate change, which was created by taking the difference between the post- and pre-intervention detection rate for each participant. Then a one-way ANOVA was performed with mean detection rate change as the dependent variable and with group as the independent variable.

This analysis showed that for mean detection rate change, the effect of group was significant ($p=0.002$), with the mean detection rate change of both Group 2 ($p=0.006$) and Group 3 ($p=0.003$) being significantly less negative than that of Group 1. There was not a significant difference in mean detection rate change between Group 2 and Group 3. The assumption of homogeneity of variances for this analysis was not met.

Stated in terms of tasks performed during the intervention period, the group which performed the New Aggie Information Helpline task and the group which rested, both had a significantly less negative mean detection rate change than the group which performed the driving task continuously. There was not a significant difference in mean detection rate change between the helpline task group and the rest break group. See Table 7.3 and Figure 7.5 for a summary of these results.

Table 7.3 Statistical results for detection rate change (for driving task)

One-Way ANOVA for Detection Rate Change						
	Sum of Squares	**df**	**Mean Square**	**F**	**p**	**η_p^2**
Group	0.082	2	0.041	8.221	**0.002**	0.37
Note: Type II Sum of Squares						

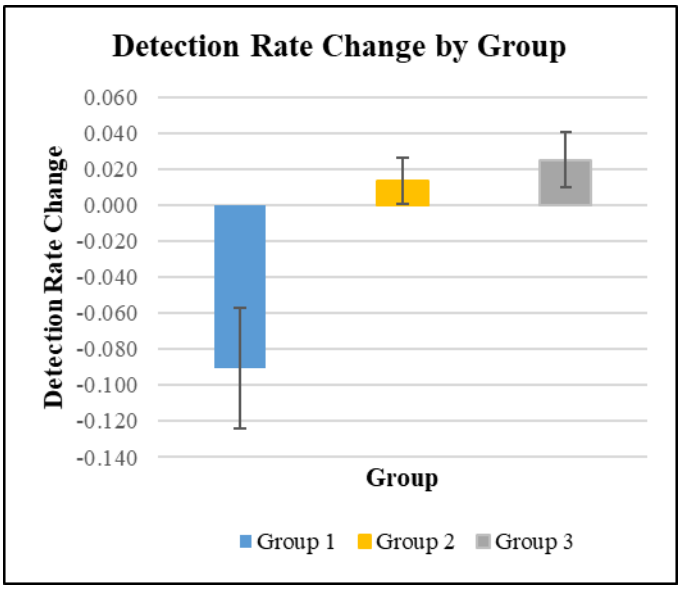

Figure 7.5 Mean values of detection rate change, divided by group, with error bars representing standard error of the mean (for driving task)

7.3.1.3. Lane Deviation

For lane deviation, neither of the two main effects nor the interaction were significant. However, post-hoc tests showed that for the post-intervention period, the mean lane deviation for Group 2 was significantly lower than that of Group 1 ($p=0.028$). No significant difference was shown to exist between Group 3 and the other two groups. The assumption of homogeneity of covariances for this analysis was not met.

Stated in terms of tasks performed during the intervention period, the group which performed the New Aggie Information Helpline Task has a significantly lower post-intervention mean lane deviation than the group which performed the driving task continuously. There was no significant difference in mean lane deviation between the group which rested and the other two groups. See Table 7.4 and Figure 7.6 for a summary of these results.

Table 7.4 Statistical results for lane deviation (for driving task)

Mixed ANOVA for Lane Deviation						
	Sum of Squares	**df**	**Mean Square**	**F**	**p**	**η_p^2**
Period	<0.001	1	<0.001	<0.001	1.00	<0.001
Group	1.045	2	0.523	1.898	0.106	0.119
Period x Group	0.169	2	0.085	2.051	0.184	0.128
Note: Type III Sum of Squares						

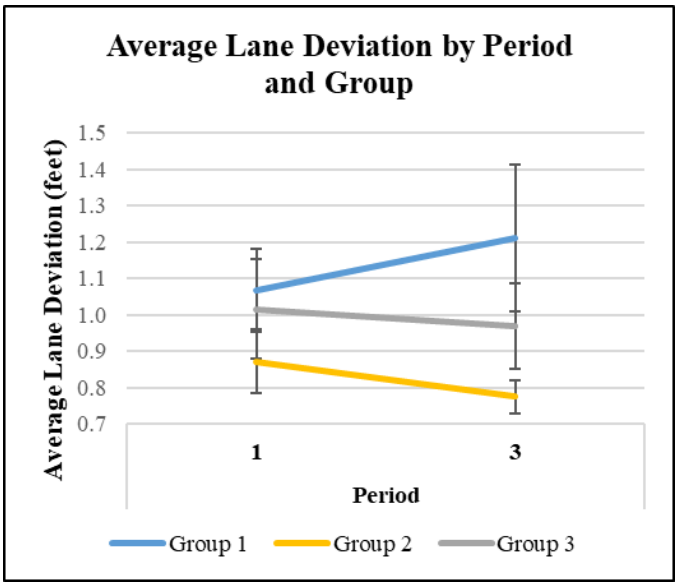

Figure 7.6 Mean values of lane deviation, divided by period and group, with error bars representing standard error of the mean (for driving task)

7.3.2. Subjective Measures

Additional analyses were performed on the subjective ratings response data. Again, mixed ANOVA was used to allow for comparisons of groups (between-subjects), periods (within-subjects), and their interaction. The analyses checked whether there was a difference in subjective ratings between groups from pre-intervention to post-intervention given that the three groups performed different tasks during the intervention period. Note that while the analyses for vigilance task performance made the comparisons between Period 1 and Period 3, the subjective ratings comparisons were between Period 0 (before the first vigilance task) and Period 3.

7.3.2.1. Mental Demand

For mental demand, the data did not meet the assumption of homogeneity of variance, so prior to performing mixed ANOVA the dependent variable was transformed according to the following formula.

$$f(x) = \sqrt[2]{x}$$

Following the transformation, the data met the homogeneity of variance assumption.

For the transformed mental demand measure, the main effect of period was significant ($p<0.001$). Looking at the non-transformed data, the mean mental demand across all groups increased from 36.4 in Period 0 to 69.4 in Period 3.

7.3.2.2. Physical Demand

For physical demand, the main effect of group ($p=0.012$) and the main effect of period ($p=0.030$) were significant. Pairwise comparisons showed that the pre-intervention mean demand for Group 1 (50.2) was significantly higher than for both Group 2 (24.2; $p=0.025$) and Group 3 (24.7; $p=0.032$).

7.3.2.3. Temporal Demand

For temporal demand, the interaction was significant ($p=0.024$), with post-hoc tests showing that the pre-intervention mean temporal demand for Group 2 (31.5) was significantly lower ($p=0.009$) than for Group 1 (60.2).

7.3.2.4. Performance

For perceived performance, the main effect of group (p=0.045) and the main effect of period (p=0.005) were significant. Pairwise comparisons showed that the post-intervention mean perceived performance measure for Group 1 (58.6) was significantly higher than for both Group 2 (40.8; p=0.022) and Group 3 (35.3; 0.004).

7.3.2.5. Effort

For effort, the main effect of period was significant (p=0.001), with post-hoc tests showing that the mean pre-intervention effort measure for Group 1 (59.5) was significantly higher (p=0.016) than for Group 2 (34.8).

7.3.2.6. Frustration

For frustration, the main effect of period was significant (p=0.011), with the mean frustration measure increasing from 33.0 in Period 0 to 49.1 in Period 3.

7.3.2.7. Boredom

For boredom, the main effect of period was significant (p=0.003), with post-hoc tests showing that the mean pre-intervention boredom measure for Group 2 (45.7) was significantly higher (p=0.044) than for Group 1 (21.6).

7.3.2.8. Motivation

For motivation, neither of the main effects nor the interaction were significant.

7.3.2.9. Mind-Wandering

For mind-wandering, the main effect of period was significant ($p<0.001$), with the mean mind-wandering measure increasing from 47.8 in Period 0 to 67.5 in Period 3.

7.3.3. Physiological Measures

Additional analyses were performed on the various physiological data gathered. Again, mixed ANOVA was used to allow for comparisons of groups (between-subjects), periods (within-subjects), and their interaction. The analyses checked whether there was a difference in physiological measures between groups from pre-intervention to post-intervention given that the three groups performed different tasks during the intervention period. Note that, like the vigilance task performance comparisons, the comparisons for the physiological data were done between Period 1 and Period 3.

7.3.3.1. Average Heart Rate

For average heart rate, the main effect of period was significant ($p=0.002$), with the mean heart rate across all groups decreasing from 81.8 bpm in Period 1 to 80.3 bpm in Period 3.

7.3.3.2. pNN50

For pNN50, the data did not meet the assumption of normality, so prior to performing mixed ANOVA the dependent variable was transformed according to the following formula.

$$f(x) = \sqrt[2]{x}$$

Following the transformation, the data approximately met the normality assumption.

For the transformed pNN50 data, neither of the main effects nor the interaction were significant. In terms of non-transformed data, the mean pNN50 across all groups and all periods was 13.5%.

7.3.3.3. RMSSD

For RMSSD, the data did not meet the assumption of normality, so prior to performing mixed ANOVA the dependent variable was transformed according to the following formula.

$$f(x) = \log_{10}(x)$$

Following the transformation, the data approximately met the normality assumption, but assumption of homogeneity of covariances was not met.

For the transformed RMSSD measure, the main effect of period was significant (p=0.037). Looking at the non-transformed data, the mean RMSSD across all groups decreased from 50.9 ms in Period 1 to 49.6 ms in Period 3.

7.3.3.4. Blink Rate

Prior to running the analysis, data values greater than 30 blinks per minute were removed from the data set, with any values exceeding this threshold assumed to be due to an error in data collection. For blink rate (blinks per minute) the data did not meet the

assumption of homogeneity of variance, so prior to performing mixed ANOVA the dependent variable was transformed according to the following formula.

$$f(x) = \sqrt[2]{x}$$

Following the transformation, the data met the homogeneity of variance assumption.

For the transformed blink rate, neither of the main effects nor the interaction were significant. In terms of non-transformed data, the mean blink rate across all groups and all periods was 10.2 blinks per minute.

7.3.3.5. Average Blink Duration

For average blink duration neither of the main effects nor the interaction were significant. The mean blink duration across all groups and all periods was 0.214 seconds.

7.3.3.6. Average Pupil Diameter

Prior to running the analysis, data values greater than 10 mm were removed from the data set, with any values exceeding this threshold assumed to be due to an error in data collection. For average pupil diameter, the main effect of group ($p=0.025$), the main effect of period ($p<0.001$), and the interaction ($p=0.013$) were significant. Post-hoc tests showed that the pre-intervention mean pupil diameter for Group 3 (7.99 mm) was significantly higher ($p=0.009$) than that of Group 1 (6.62 mm). For post-intervention, the mean pupil diameter for Group 3 (7.61 mm) was significantly higher than that of both Group 1 (6.58 mm; $p=0.028$) and Group 2 (6.39 mm; $p=0.019$).

7.3.4. Analysis of Intervening Task

As with the first experiment, analyses of changes in the collected subjective ratings assumed to be related to energetic arousal and the intrinsically rewarding nature of the task were completed. In addition, similar analyses were performed on the three heart-related physiological measures. Eye movement-related measures were not captured during the intervention period and were therefore not available for this analysis. These analyses were performed to infer changes in arousal and perceived rewarding nature of the tasks from Period 1 (when the original vigilance task was performed) to Period 2 (when the different intervening tasks were performed). Again, the collected measures assumed to be related to arousal are boredom and motivation, while the measures of boredom, motivation, and mind-wandering are assumed to be indicative of the intrinsically rewarding nature of the intervening task. For this experiment, only one group (Group 2) performed an intervening task.

7.3.4.1. Boredom

For Group 2, there was a significant decrease ($p=0.001$) in the mean boredom measure from Period 1 (57.8) to Period 2 (21.6).

7.3.4.2. Motivation

For Group 2, there was not a significant change in the motivation measure from Period 1 to Period 2.

7.3.4.3. Mind-Wandering

For Group 2, there was a significant decrease ($p<0.001$) in the mean mind-wandering measure from Period 1 (66.8) to Period 2 (26.5).

7.3.4.4. Average Heart Rate

For Group 2, there was not a significant change in average heart rate from Period 1 to Period 2.

7.3.4.5. pNN50

For pNN50, the data did not meet the assumption of normality, so prior to performing repeated measures ANOVA the dependent variable was transformed according to the following formula.

$$f(y) = \sqrt[2]{\alpha - y}$$

where $\alpha = max\{y_1 + 1, \ldots y_N + 1\}$

where $y = f(x) = \sqrt[2]{x}$

Following the transformation, the data approximately met the normality assumption.

For Group 2, there was not a significant change in the transformed pNN50 from Period 1 to Period 2.

7.3.4.6. RMSSD

For RMSSD, the data did not meet the assumption of normality, so prior to performing repeated measures ANOVA the dependent variable was transformed according to the following formula.

$$f(y) = \sqrt[2]{\alpha - y}$$

where $\alpha = max\{y_1 + 1, \ldots y_N + 1\}$

where $y = f(x) = \sqrt[2]{x}$

Following the transformation, the data approximately met the normality assumption.

For Group 2, there was not a significant change in the transformed RMSSD from Period 1 to Period 2.

7.4. Discussion

To answer Question 5, therefore, results from this study indicate that rotating to a task of contrasting demands is as effective, if not better, than a passive rest break in lessening the decrease in semi-autonomous vigilance driving task performance. It should be recognized however, that unlike driving many properly functioning semi-autonomous vehicles, this experimental driving task required repetitive input in response to numerous simulated automation errors. This task demand of repetitive input was experimentally needed to be able to determine the participant's level of sustained attention to the driving task.

Statistically speaking, the effectiveness of the task rotation on performance within the driving environment was not as clear as it was within the basic experiment

setting. Several different factors could serve as explanations for these differing results as will be discussed in the conclusions chapter.

In terms of subjective ratings, mental demand, frustration, and mind-wandering significantly increased for all groups from pre- to post-intervention, which follows expectations. Significant post-intervention group differences include the temporal demand of Group 2 being less than that of Group 1 and the perceived performance of Group 1 being greater than that of Groups 2 and 3. It follows expectation that the post-intervention temporal demand for the group which performed the Aggie Helpline task was lower than for the group which performed only the driving task. However, going against expectations was that the post-intervention perceived performance of the group which only drove was greater than both the group which performed the Aggie Helpline task and the group that rested.

In terms of physiological measures, there were no significant differences for the measures of pNN50, blink rate, and average blink duration. There were significant decreases pre- to post-intervention for both average heart rate and RMSSD. As covered in the literature review, this decrease in heart rate could indicate an increase in driver monotony (the opposite of increased workload). However, also informed by the literature, the decrease in RMSSD (a measure of heart rate variability) indicates increased workload. Therefore, these two heart rate measures give conflicting indications of the impact of performing the experimental tasks. For average pupil diameter, Group 3 was significantly larger than Group 2 post-intervention. With the literature linking decreased pupil diameter with increased fatigue, this difference could

indicate that in terms of this physiological response, the group which performed the Aggie Helpline task was more fatigued post-intervention than the group which rested.

The analyses performed to infer whether the intervening task met the desired qualities of increasing energetic arousal and being intrinsically rewarding revealed significant changes in boredom and mind-wandering, with both decreasing during the intervening task. This may imply that the intervening task did indeed lead to an increase in energetic arousal and was perceived as more intrinsically rewarding in comparison to the original vigilance task. The lack of significant physiological changes hinders stronger interpretations of possible changes in energetic arousal.

8. CONCLUSIONS

With the rise in automation, the number of jobs requiring vigilance task performance is likely to increase. And given the safety implications of many of these jobs, it is imperative that additional solutions be developed to combat the vigilance decrement. This research work has demonstrated a new possible countermeasure to fatigue for vigilance-type tasks which has the added benefit of allowing worker productivity to remain high while still recovering from fatigue. The details of the conclusions drawn from this study are organized by their respective research questions below.

8.1. Research Question 1

Based on the results from the experiment it was determined that the use of rotation to a task of contrasting demands can serve as an effective countermeasure to the vigilance decrement. This effectiveness was demonstrated even when the effectiveness of a passive rest break was not, indicating that the use of a properly designed intervening task may be more effective than even a rest break.

8.2. Research Question 2

Results from group performance comparisons led to the conclusion that the effectiveness of the original task rotation was insignificantly impacted by the contrast of

demands in terms of **perceptual modality**, but instead must be attributed to the other contrasting task dimensions or other task characteristics not considered by our model.

8.3. Research Question 3

Results from group performance comparisons led to the conclusion that the effectiveness of the original task rotation was insignificantly impacted by the contrast of demands in terms of **processing code**, but instead must be attributed to the other contrasting task dimensions or other task characteristics not considered by our model.

8.4. Research Question 4

Results from group performance comparisons led to the conclusion that the effectiveness of the original task rotation was significantly impacted by the contrast of demands in terms of **predominant processing stage**. Still unexplored are the impacts of other task characteristics not considered by our model.

8.5. Research Question 5

Based on the results from the driving task experiment it was determined that the use of rotation to a task of contrasting demands can serve as an effective countermeasure to cognitive fatigue within a simulated semi-autonomous driving environment. While this effectiveness was in some measures matched by the effectiveness of a passive rest break, the use of the intervening task has the added real-world application benefit of increased productivity in comparison to taking a rest break.

8.6. Summary of Findings

Overall findings from this body of research work generally matched expectations stated in the pre-experiment hypotheses. Experiment results demonstrated fairly strong evidence of the effectiveness of task rotation as a countermeasure to the vigilance decrement specifically and perhaps to cognitive fatigue more generally, both in a controlled experimental environment and a more applied environment. Conclusions drawn concerning the effectiveness of each dimension of task demands were not quite as clear, but the strongest indication is that the effectiveness of the task rotation was primarily due to the contrast in predominant processing stage demanded by the tasks. It is certainly possible that task characteristics outside the consideration of our task demand model may partially or wholly be the underlying cause of the task rotation effectiveness. Indeed, of the three dimensions of our task demand model, the processing stage is the least precise. It must be remembered that while the investigation into the underlying task characteristics impacting the effectiveness of the task rotation focused on the cognitive demands within the framework of the multiple resource theory, additional task characteristics were hypothesized as being critical to the effectiveness of the intervening task. Stated again, it was proposed that the intervening task should be one which: (1) places cognitive resource demands on the human which are different than those of the vigilance task, (2) leads to an increase in arousal when performed, (3) naturally draws attention to itself and/or is intrinsically rewarding, and therefore (4) does not require as much top-down attentional control (self-regulation), and hence (5) requires much less effort. It is less clear from both the task demand model used and the

experiment results whether each of intervening tasks used in the experiments met task characteristics (2)-(5). In particular for (2) increasing arousal, the lack of physiological data collected in the experiments for Questions 1-4 makes the determination of any changes in participants' energetic arousal difficult. In the experiment for Question 5, while physiological data was collected, there were no significant differences between groups over time, again making interpretations of arousal level difficult. Significant changes in the subjective measures of boredom, motivation, and mind-wandering were detected in the groups which performed intervening tasks determined to be effective in lessening the vigilance decrement. It could be assumed that these measures are indicative of energetic arousal and the intrinsically rewarding nature of the intervening tasks. However, strong conclusions cannot be drawn from these changes in subjective measures, particularly for energetic arousal, unless supported by significant changes in physiological measures. Future work should investigate more precisely on these task characteristics (2)-(5) to determine the extent of their impact on the effectiveness of the original intervening task. In addition, investigations using other classification models of task characteristics can help to more precisely define the key contrasting task characteristics which are effective in alleviating cognitive fatigue when taken into account in task rotation.

8.7. Limitations

Several limitations existed for this research work. Due to COVID-19, the experiments for Questions 1-3 had to be conducted remotely. While experiment

instructions were designed to lead to a more controlled environment, the personal locations of multiple participants are inherently less controlled than a fixed laboratory setting. Thus, it is likely that additional unknown "noise" variables affected the data and results. In addition, having one group perform the experiment in-person may have led to different impacts on this group. Specifically looking at pre- and post-intervention response time for the in-person group, the mean of this measure was significantly greater than all other groups. It is speculated that the keyboard used by this group hindered response time as compared to the various keyboards used by the remote participants.

While data from at least 30 participants was able to be collected for each of Groups 1-6 in the non-driving experiments, due to time constraints, data from only 31 participants was collected for the driving experiment across all groups. This smaller sample size likely impacted the ability of the statistical analysis to determine differences which may have existed between the groups.

The different intervening tasks were chosen so that each contrasted in demands from the original vigilance task in terms of two of the three dimensions of the multiple resource model. When drawing conclusions about the effectiveness of each contrasting dimension in alleviating the vigilance decrement, it was assumed that the only differences in the four intervening tasks were these changes in dimensions. That is, the assumption is that each of the intervening tasks placed a similar level of overall workload on the participant. However, comparisons of performance measures and subjective ratings on these tasks indicated that they led to varying degrees of workload on the participants. While some degree of these differences in workload may be due to

the task differences in terms of dimensions (which is the variable of interest), other task characteristics not captured by our model may have impacted the different levels of workload imposed by each task. In addition, while the intervening tasks were chosen to be ones which applied a similar workload level to all participants, individual differences between participants likely introduced additional variability.

One variable which was not manipulated in these experiments but would likely have a significant impact is time on task for both the vigilance tasks and the intervening tasks. For experiment feasibility purposes, the task time was set to be as short as possible while still creating a fatiguing environment. Informed by previous studies as well as pilot testing, 10 minutes was selected as the minimum task time for which the vigilance decrement was expected to occur (and become measurable). The time period for the intervening task was also set at 10 minutes to make each period consistent in duration. Future studies can explore the impact of changes in task time for both the vigilance task as well as the intervening tasks. For example, it could be tested whether performing an intervening task for just five minutes is as effective as performing it for 10 minutes.

8.8. Practical Applications

It is hoped that, if supported by future research, this body of research will change the way that jobs are designed so as to alleviate cognitive fatigue and increase worker productivity. Research into countermeasures to physical fatigue has led to recommendations for physically demanding jobs to be designed to not place repeated demands on the same biomechanical subsystems for the full duration of a work shift, but

rather to rotate between tasks of different demands so as to lessen fatigue of particular subsystems. In a similar manner, this research direction may lead to recommendations for including task rotation in the design of cognitively demanding jobs in order to reduce cognitive fatigue. More research is needed to determine the degree to which the effectiveness of the task rotation countermeasure is generalizable to tasks beyond those used in these experiments. The original vigilance task and the driving task were both tasks which did not require a high level of expertise, which is unlike many real-world vigilance tasks such as medical monitoring and air traffic control. In addition, there were no serious implications for errors committed on these experimental tasks, which also differs from many real-world applied tasks.

There are of course some potential barriers to implementation of this countermeasure in industry, as well as some potential drawbacks. The most obvious perhaps is the implication that workers would have to be trained on multiple tasks. This may not be a problem for tasks which require little training, but some tasks may require high levels of expertise which can only be acquired through extensive and costly training. Companies will likely be hesitant to have a well-trained operator perform a task which does not make use of their expensive training, while also having to train additional workers to compensate for this time away. The benefits of the task rotation countermeasure must be calculated and determined to be cost effective enough to implement before it is widely adopted. Benefits may include a decrease in operator errors which have an associated cost depending on the task. In addition to increased training costs, a potential drawback to the use of task rotation is the lessening of

experience gained in a particular task, and therefore the potential for a decrease in task expertise. This is likely most pertinent to highly complex tasks which require a high level of expertise. While it not always true, many complex tasks already place a greater variety of cognitive demands on an operator than do simple tasks, thus making rotation to a task of different demands unnecessary. The tasks for which task rotation is likely to be the most useful are those which are low in complexity (low variety in cognitive demands), which may correspond to those requiring a lower level of expertise. However, there are likely exceptions to these assumptions which must be considered as well.

The use of automation is expected to greatly increase, with many forms of automation still requiring human-in-the-loop interaction (Feng et al., 2016). Thus, the number of human tasks requiring vigilance (in the form of automation monitoring) is also likely to increase. This trend makes research into potential fatigue countermeasures such as task rotation even more imperative.

8.9. Future Research

While some aspects of the driving task may not fall completely within the definition of a vigilance task, this research work as a whole primarily focused on the effectiveness of the task rotation countermeasure applied towards a specific type of cognitive fatigue – the vigilance decrement. Hopefully future research work can explore the degree of effectiveness of this countermeasure to other types of cognitive fatigue. In particular, there are opportunities to explore other continuous tasks which do not meet the strict definition of a vigilance task. Some examples of non-vigilance continuous tasks

which have been used to study fatigue include conflict tasks (Lorist, 2008), cognitive control tasks (Wang et al., 2016), and psychometric tasks (Bohnen et al., 1990).

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APPENDIX A

PRE-EXPERIMENT (REMOTE) INSTRUCTIONS FOR GROUPS 1-3

Pre-Experiment Steps

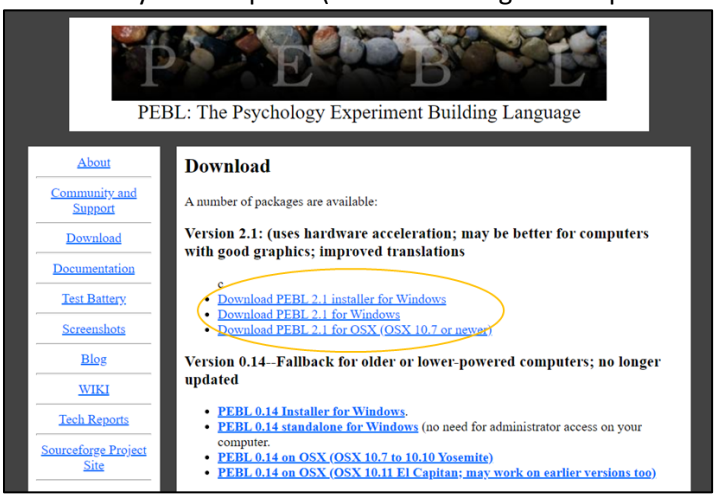
Thank you for agreeing to participate in this study. This document will guide you through the steps of preparing for the experiment.

Step 1: Sign the Consent Form
If you have not done so already, please read and sign the consent form before continuing: https://tamu.qualtrics.com/jfe/form/SV_37V2eZlJgvYUDMW

Step 2: Download and setup the needed software
This is a free software created by researchers to study human task performance. It is used by several research teams at Texas A&M and other universities.

> We understand that you may be hesitant to download an unknown software. Because it was developed to be freely used for research purposes, it does lack the professional appearance of software created for purchase. However, it has been used by several research universities as documented in the journal article (cited 558 times according to Google Scholar) attached in the last email:
>
> "The Psychology Experiment Building Language (PEBL) and PEBL Test Battery"
>
> If you still do not feel comfortable downloading the software, please contact johnathan.mckenzie@tamu.edu and tferris@tamu.edu before continuing.

To download the software, go to http://pebl.sourceforge.net/download.html and select the download option needed for your computer (circled in orange in the picture below).

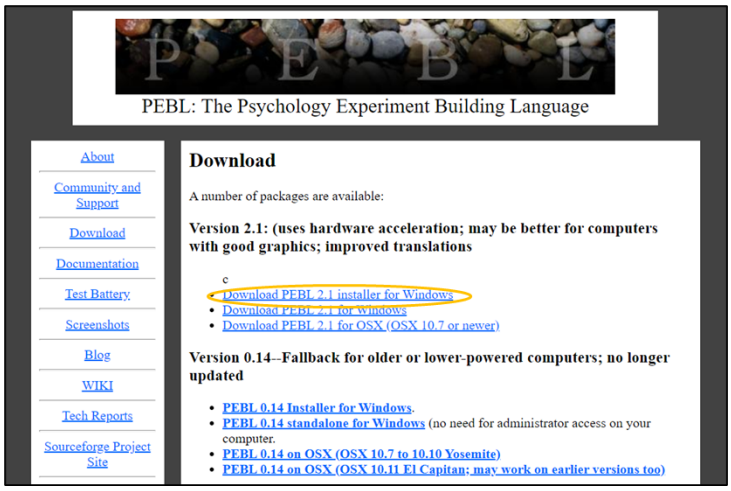


For Windows users, there are two options:

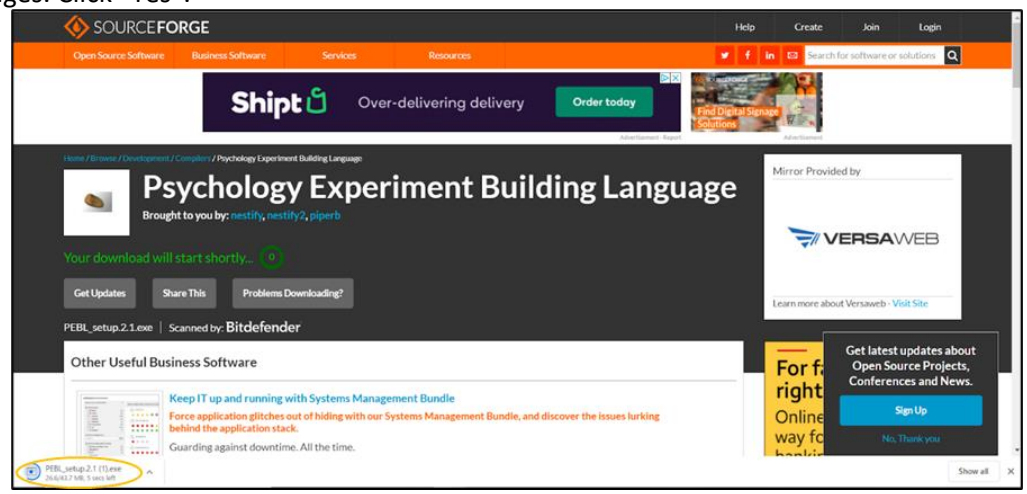
(This video (https://www.youtube.com/watch?v=YyhARjcYSew) also explains the installation process, but it is not as concise as the directions given below.)

Option 1: Use the Windows installer

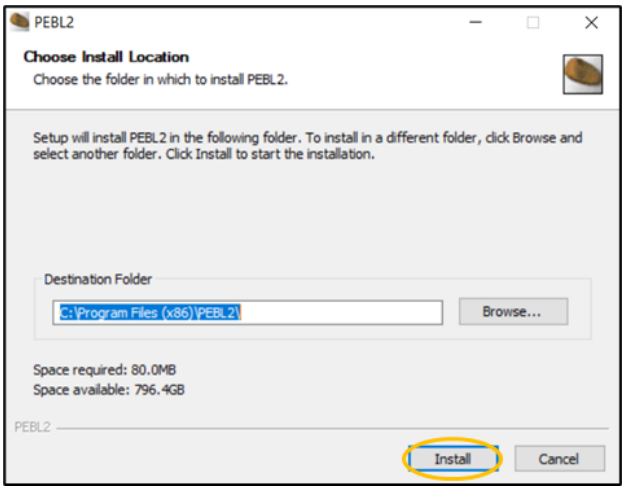
Click “Download PEBL 2.1 installer for Windows”.



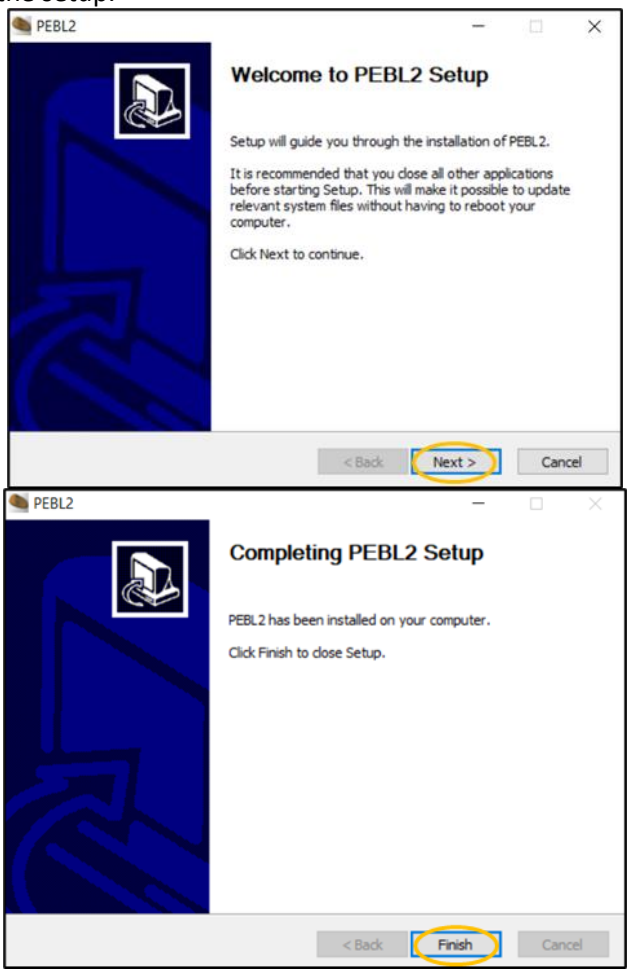
On the next screen, it will show the software beginning to download and the “PEBL_setup.2.1.exe” box should show up at the bottom left of the screen. When the download has finished, click this box and a pop-up will appear asking if you allow the app to make changes. Click “Yes”.



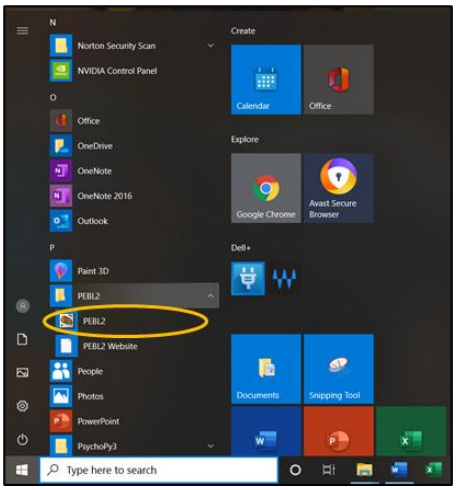
Then a second window will pop-up, asking you to choose a location to install the program. If the default folder is okay, click “Install”.



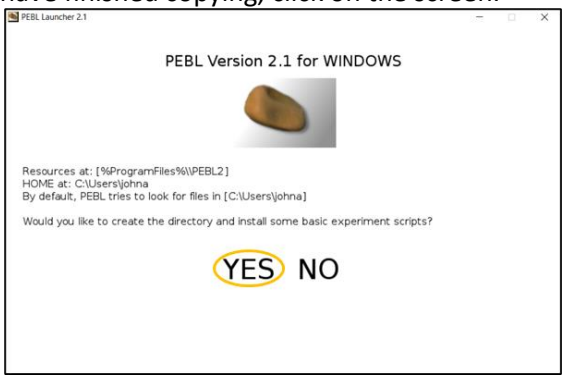
The next window will start the setup process. Click through these steps. Finally, you can click "Finish" to complete the setup.

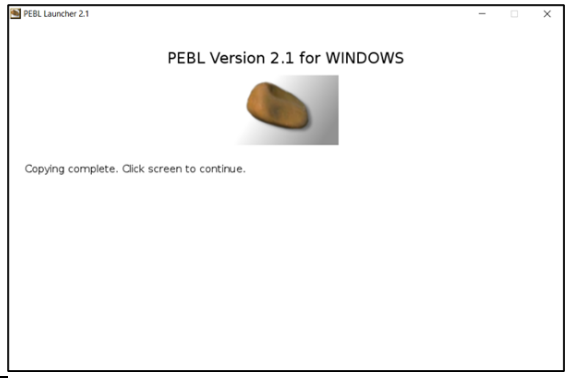


The PEBL software should now show up in your programs list. Open the program.

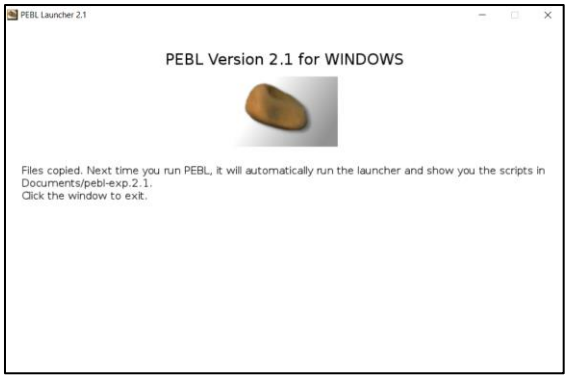


The first time you open it, you will get the window shown below. Click “YES”. When the files have finished copying, click on the screen.



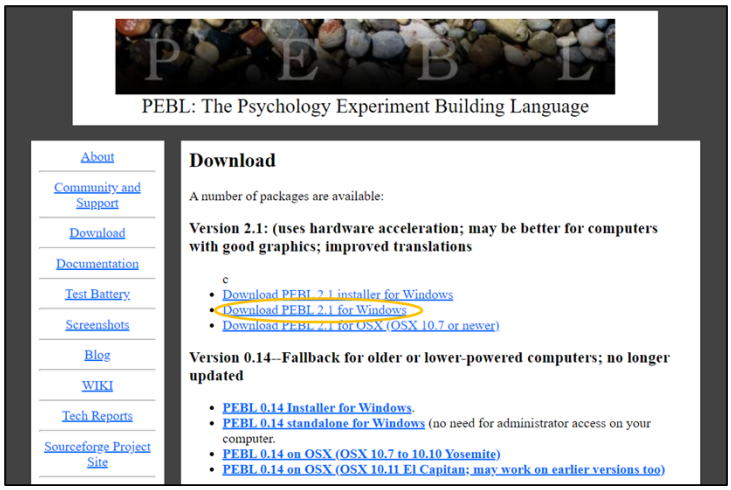


Then on the next window, click to exit.

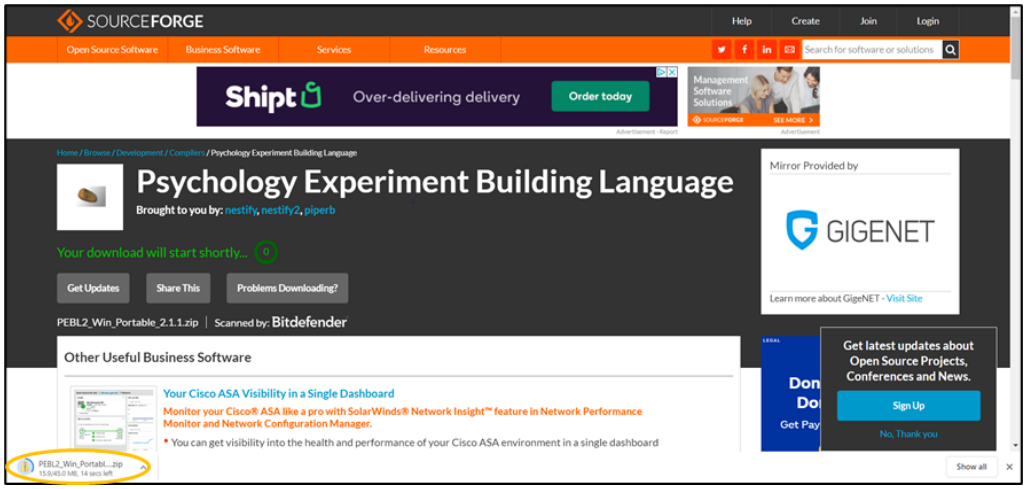


Option 2: Download and extract zip file

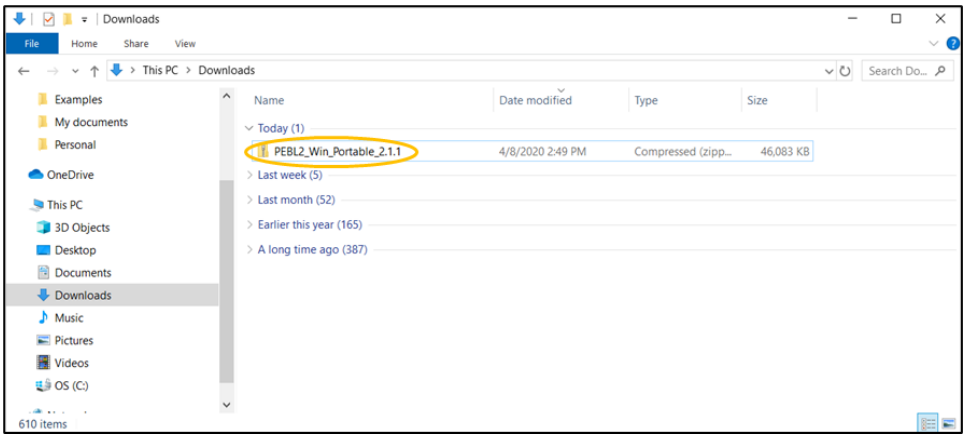
Click “Download PEBL 2.1 for Windows”.



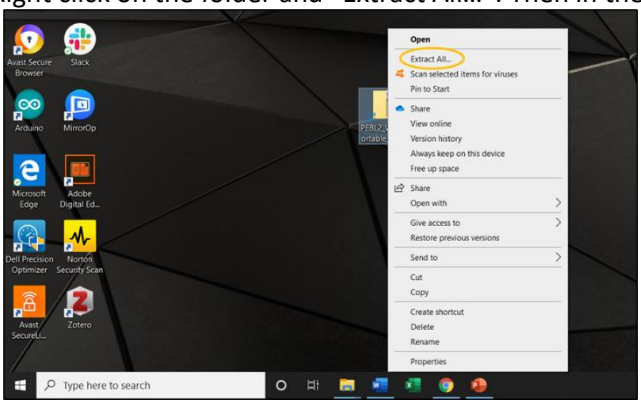
On the next screen, it will show the software beginning to download and the "PEBL2_Win_Portable_2.1.1" zip folder box should show up at the bottom left of the screen. Wait for the folder to download.

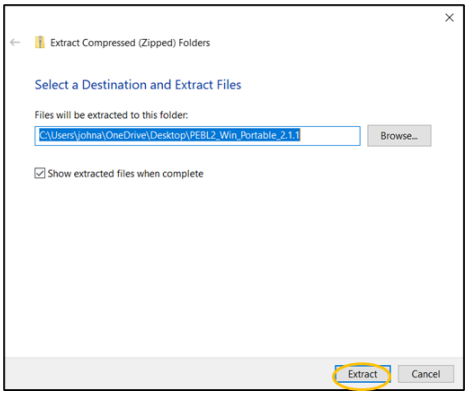


Go to your downloads folder and find this zip folder. Move the folder to your desktop.

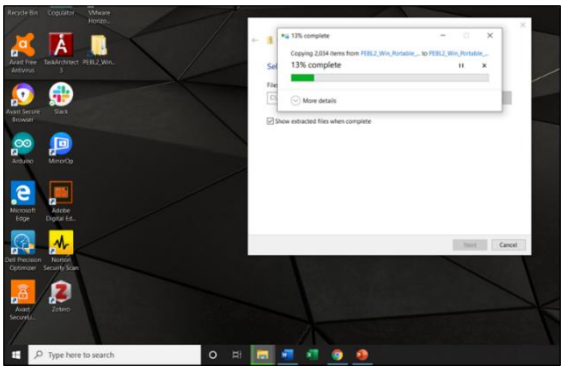


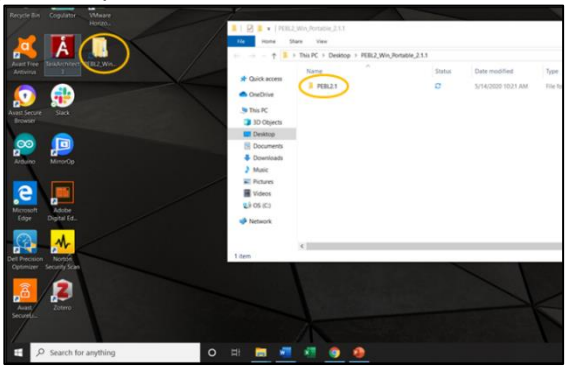
Right click on the folder and “Extract All…”. Then in the new window, click “Extract”.



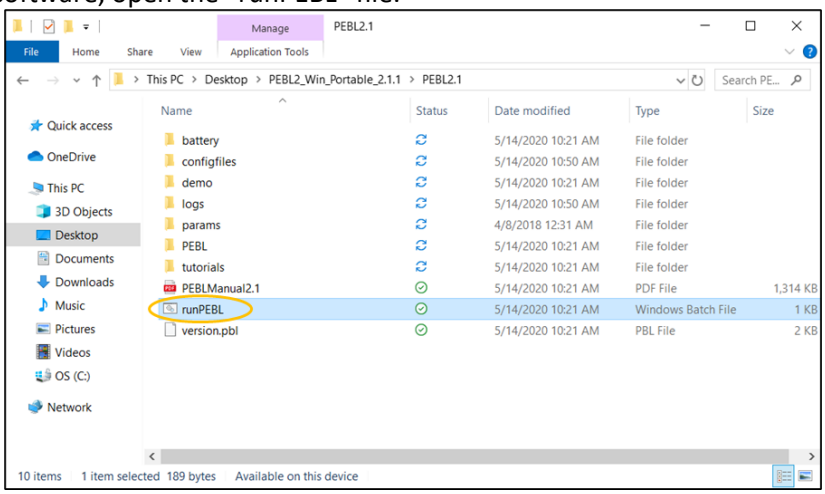


Wait for the files to extract. Then the extracted folder should pop-up (or the icon will show on your desktop). Within the “PEBL_Win_Portable_2.1.1”, open the “PEBL2.1” folder.





To open the software, open the “runPEBL” file.



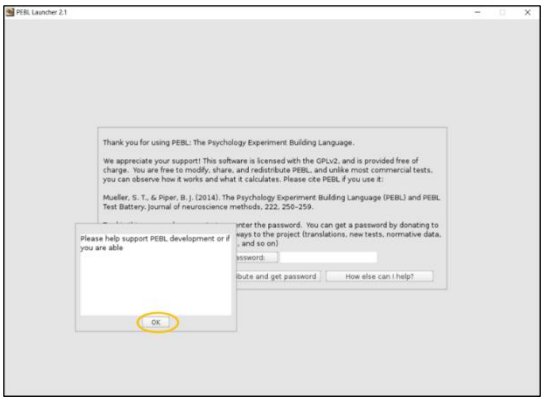
For Mac (OSX) users, there is just one option:

Please watch this video for instructions: https://www.youtube.com/watch?v=SLvmger55ok

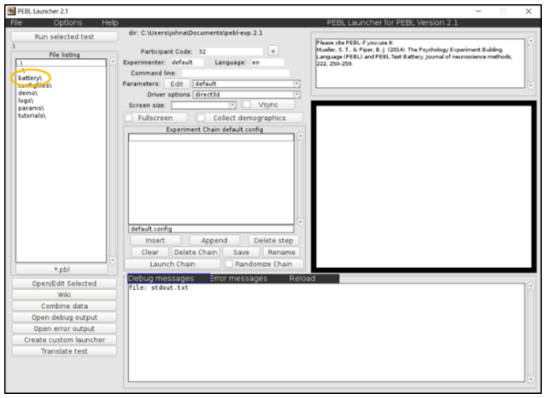
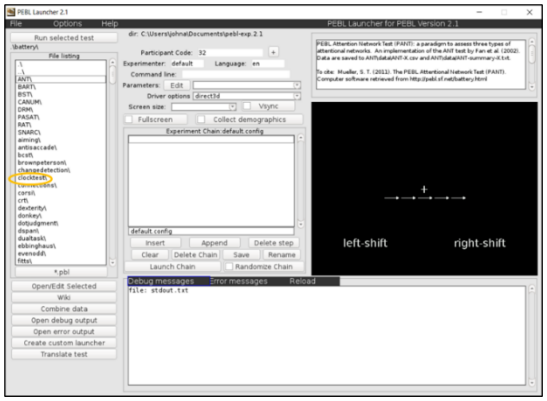
In addition to learning how to download and run the software, pay attention to where the video tells you that your data will be stored (within the “battery” folder). Later you will need to obtain your data and email it to the research team.

Step 3: Try out the PEBL software and complete the practice session

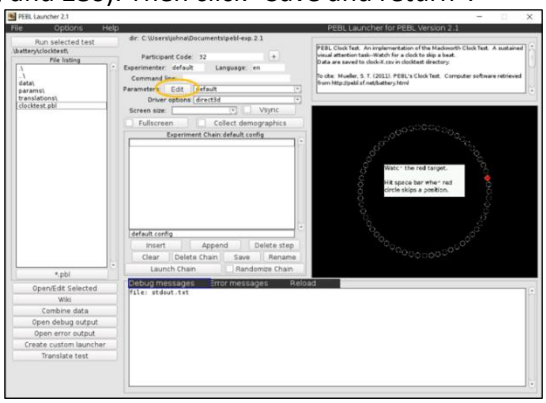
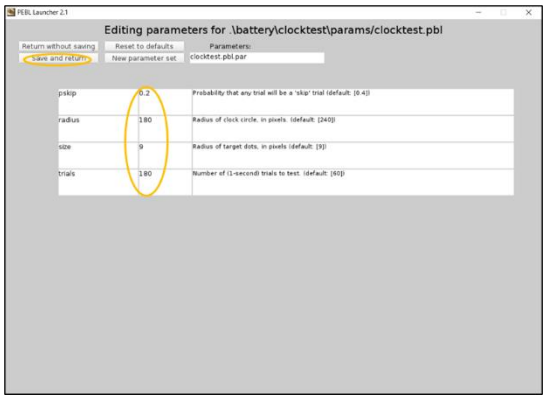
When you open the PEBL software, it will show a window in which it asks for a password. Just click “Use without password”. A pop-up will appear, and you can just click “OK”.



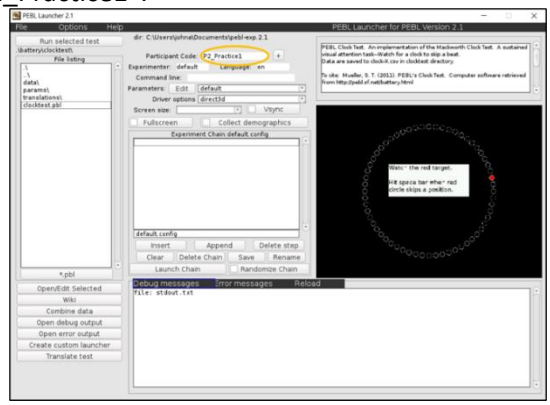
The next window is the main screen. Double-click on “battery\”. Then double-click on “clocktest\”.

In the next window, click the “Edit” button to change the parameters. In this window, change the numbers (circled in orange) to be the same as those shown in the picture below (**0.2**, **180**, **9**, and **180**). Then click “Save and return”.

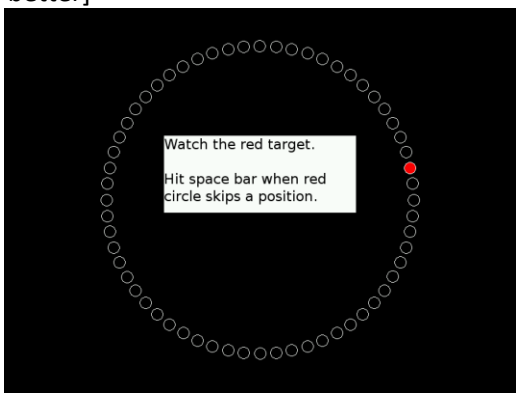
You will now be back at the previous window. In the “Participant Code” box, type in “**P#_Practice1**” with your participant number in place of the “#”. For example, if you are participant 2, type in “P2_Practice1”.



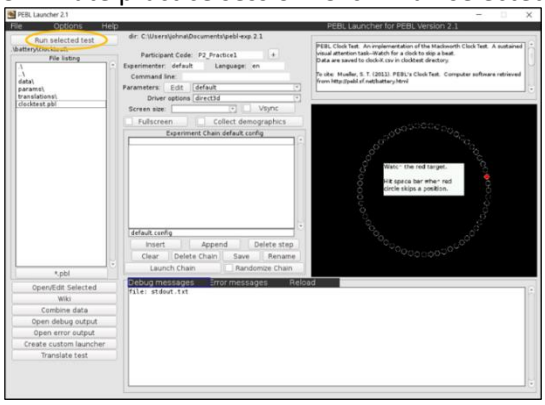
Everything is now setup for you to complete a practice session of the task. Before you begin, here is an explanation of how to perform the task.

You will be watching a screen like the one shown below. The red target (dot) will move from one position (white circle) to the next every second, similar to how the second hand moves around a clock. Sometimes the red dot will skip a circle. When this happens, you should press the space bar as quickly as you can. If the red dot does not skip a circle, then you should *not* press the space bar (do not do anything). Your performance will be graded on the following measures:

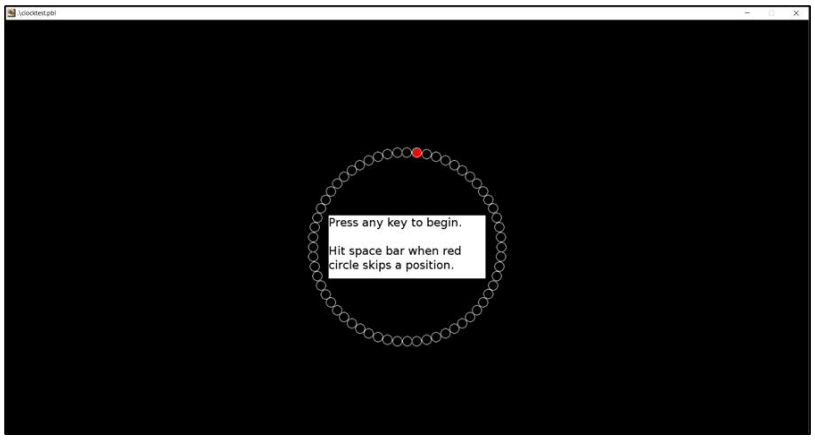
Detection rate: Percentage of skips you detect (by pressing the space bar) [higher is better]
Reaction time: The time it takes you to press the space bar when a skip occurs [lower (quicker) is better]
False alarms: The number of times you press the space bar when a skip has not occurred [fewer is better]



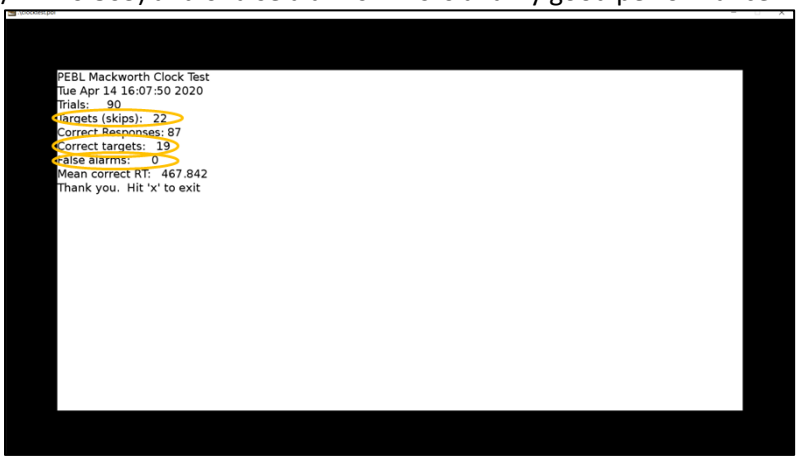
Now you will complete a 3-minute practice session. Click “Run selected test”.



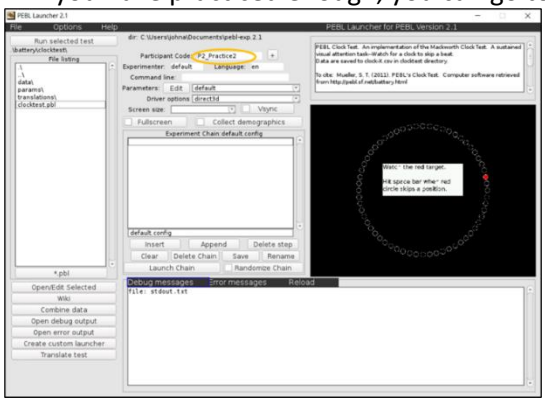
This window will pop-up. As it says in the center, you can press any key to begin. After 3 minutes, the task will automatically end. Note: You are not able to pause the task once it starts.



When the task ends, a screen like this will pop-up which shows your results. In the example below, there were 22 skips, 19 of which were detected, so this person had a detection rate of about 86% (19/22 = 0.863) and 0 false alarms. This is a fairly good performance.



If your detection rate was less than 85%, and/or if you had several false alarms, we recommend that you re-do the practice session and improve your score before continuing. Just update the "Participant Code" box to be "**P#_Practice2**" for your 2nd practice session and so forth (see picture below). If you did not understand the directions, you can re-read them before retrying the practice. When you think you have practiced enough, you can go to the next step.



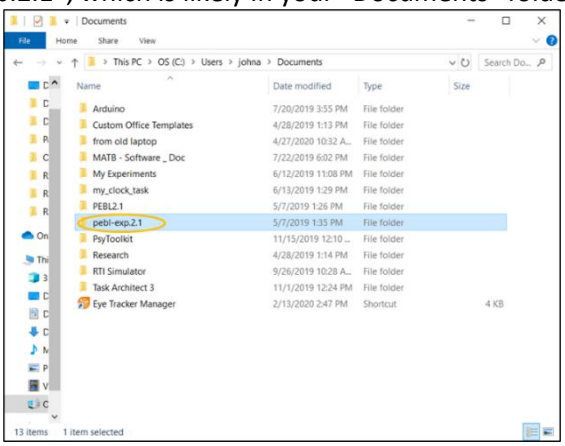
Step 4: Find and email practice data

The PEBL software automatically saves your task data to a folder on your computer.

The location of the data will depend on which option you used to download the software.

Folder location for Option 1:

Find the folder “pebl-exp.2.1”, which is likely in your “Documents” folder.



When you find the folder, open it, and follow the following folder path:

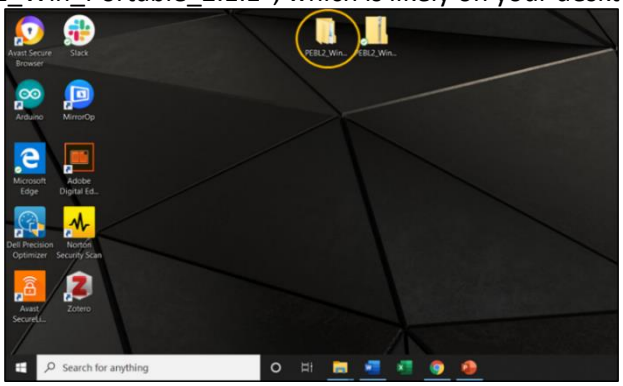
battery

clocktest

data

Folder location for Option 2:

Find the folder “PEBL2_Win_Portable_2.1.1”, which is likely on your desktop.



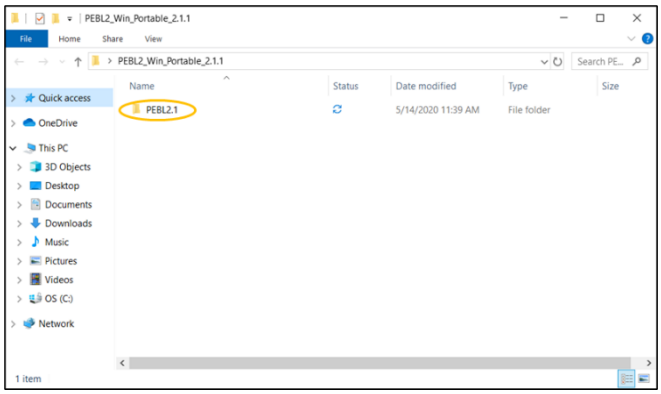
In this folder follow the following folder path:

PEBL2.1

battery

clocktest

data



Folder location for Mac (OSX) Option:
Please watch this video for instructions: https://www.youtube.com/watch?v=SLvmger55ok

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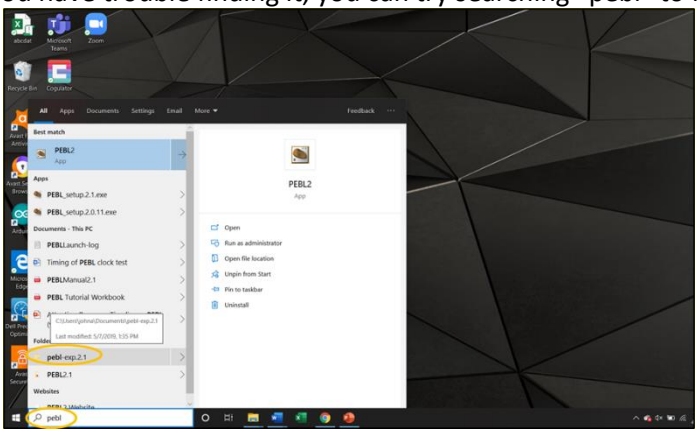
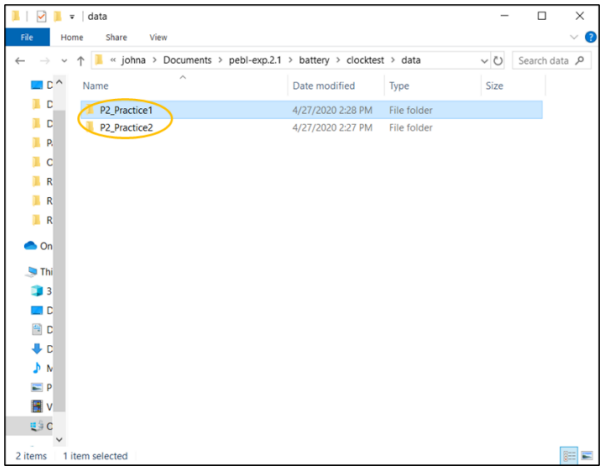
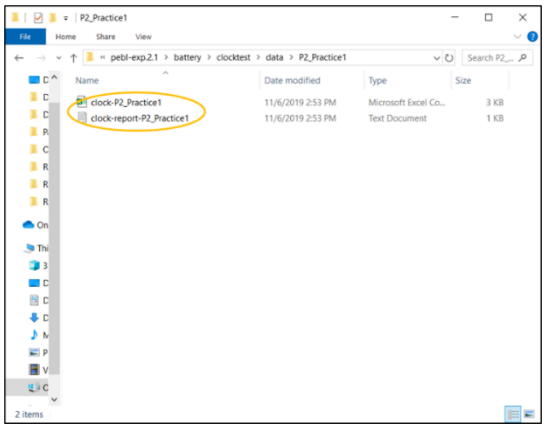
For any option, if you have trouble finding it, you can try searching “pebl” to find it.



Once you get in the “data” folder, you should see one or more folders which contain your practice data. So, if you had two practice sessions, you should have two folders (as in the picture below).

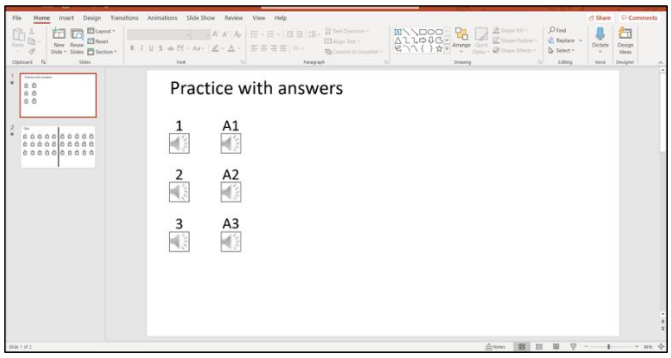


Opening one of the folders, you should see two files. For *each* folder, these files need to be emailed to the research team (tamu.attention.study@gmail.com). You can go ahead and email your practice files or wait and email all your files together after you complete the full task session.



Step 5: Try out the other task and complete the practice session

The other task you may complete during the experiment is the Remote Associates Test (RAT). Open the PowerPoint file "RAT Task - Auditory". The file will contain two slides, the first for practicing.



Instructions: You will click a play button and listen to the recording of three words. Next, think of a fourth word that is related to each of the first three words.

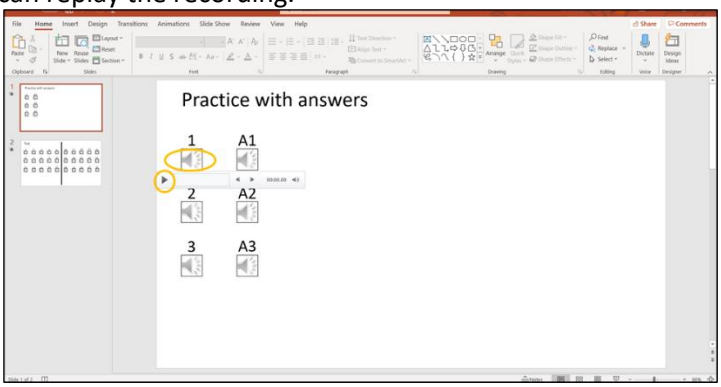
Here is an example:

envy / golf / beans Correct answer: green

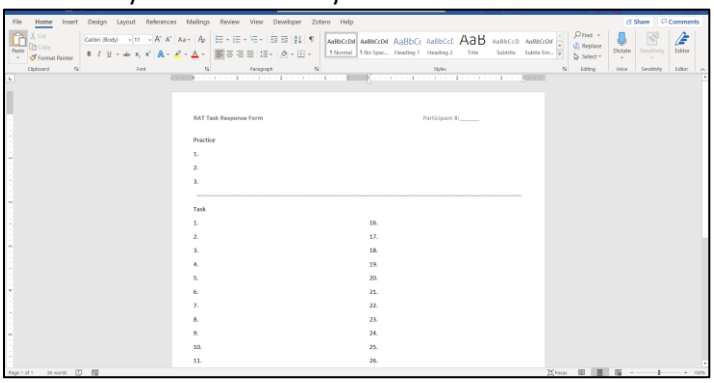
Although envy, golf, and beans do not really relate to each other, they each relate to green in a way. "Green with envy" is a common phrase to describe jealousy. One area of a golf course is the "green". And then "green beans" are a type of vegetable. As you can see, the words can relate to each other in different ways.

Now you can complete the practice groups of words. On the first slide, there are three practice recordings and their corresponding answers. Under "1", hover your cursor over the speaker

symbol and then a play button will appear. Click the play button to listen to the recording. If you need to, you can replay the recording.



After you have listened to the words, take your time to try to think of a word that relates to them all. Then type your answer in the document "RAT Task Response Form" (see below). You can guess or leave it blank if you do not think you have an answer.



When you are ready to hear the answer, play the recording under "A1" on the first slide. Then try to complete only the other two practice recordings. When you have finished the practice recordings, *save* the "RAT Task Response Form".
Do not complete the other recordings (on the second slide) at this time.

Summary of Steps:

Step 1: Sign the Consent Form
Step 2: Download and setup the needed software
Step 3: Try out the PEBL software and complete the practice session
Step 4: Find and email practice data
Step 5: Try out the other task and complete the practice session

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If you have completed the above steps, then you have finished the pre-experiment. When you are ready, you can go to the next document "Experiment Instructions".

APPENDIX B

PRE-EXPERIMENT (REMOTE) INSTRUCTIONS FOR GROUP 4

Pre-Experiment Steps

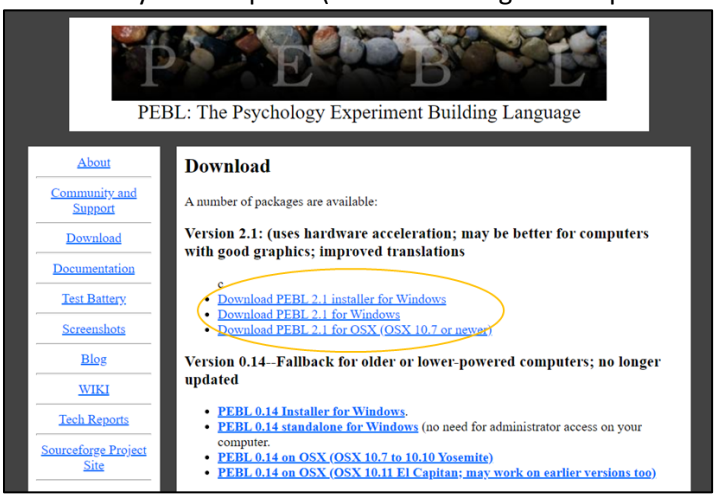
Thank you for agreeing to participate in this study. This document will guide you through the steps of preparing for the experiment.

Step 1: Sign the Consent Form
If you have not done so already, please read and sign the consent form before continuing: https://tamu.qualtrics.com/jfe/form/SV_37V2eZlJgvYUDMW

Step 2: Download and setup the needed software
This is a free software created by researchers to study human task performance. It is used by several research teams at Texas A&M and other universities.

> We understand that you may be hesitant to download an unknown software. Because it was developed to be freely used for research purposes, it does lack the professional appearance of software created for purchase. However, it has been used by several research universities as documented in the journal article (cited 558 times according to Google Scholar) attached in the last email:
>
> "The Psychology Experiment Building Language (PEBL) and PEBL Test Battery"
>
> If you still do not feel comfortable downloading the software, please contact johnathan.mckenzie@tamu.edu and tferris@tamu.edu before continuing.

To download the software, go to http://pebl.sourceforge.net/download.html and select the download option needed for your computer (circled in orange in the picture below).

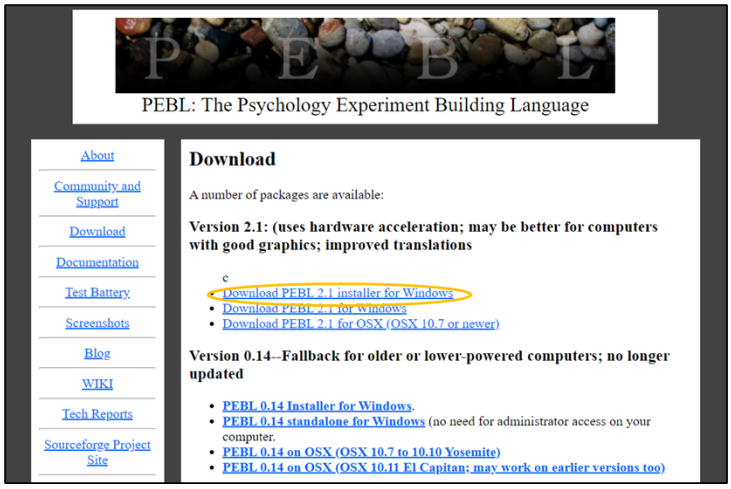


For Windows users, there are two options:

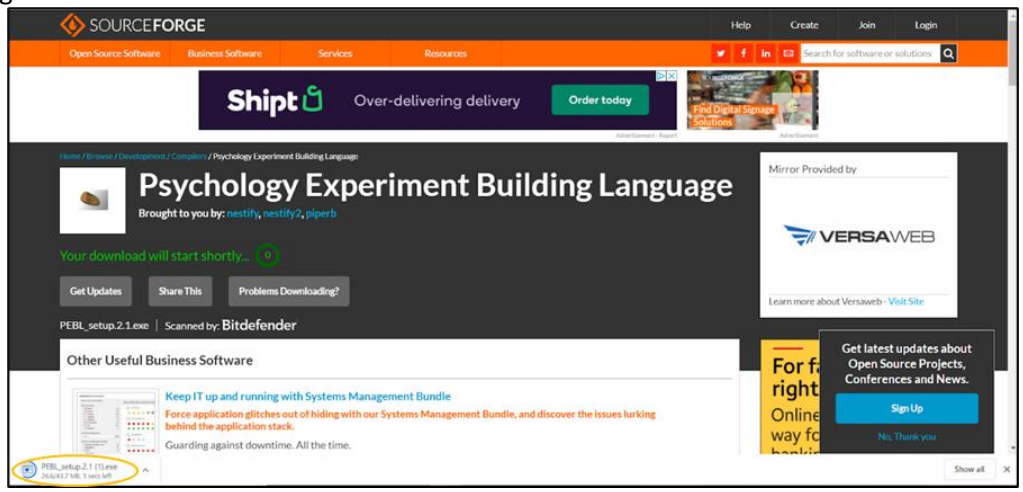
(This video (https://www.youtube.com/watch?v=YyhARjcYSew) also explains the installation process, but it is not as concise as the directions given below.)

Option 1: Use the Windows installer

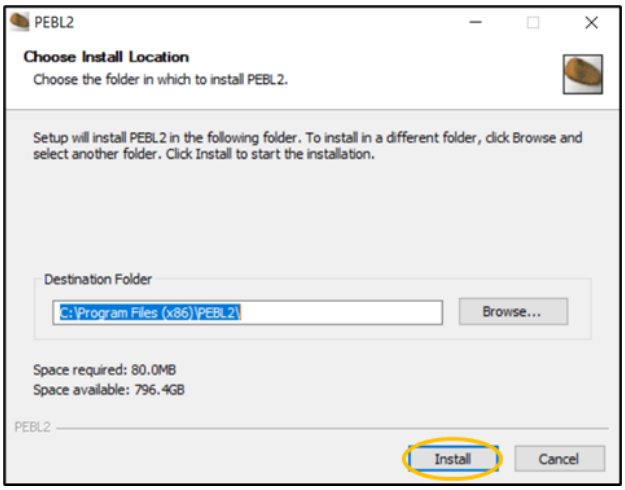
Click “Download PEBL 2.1 installer for Windows”.



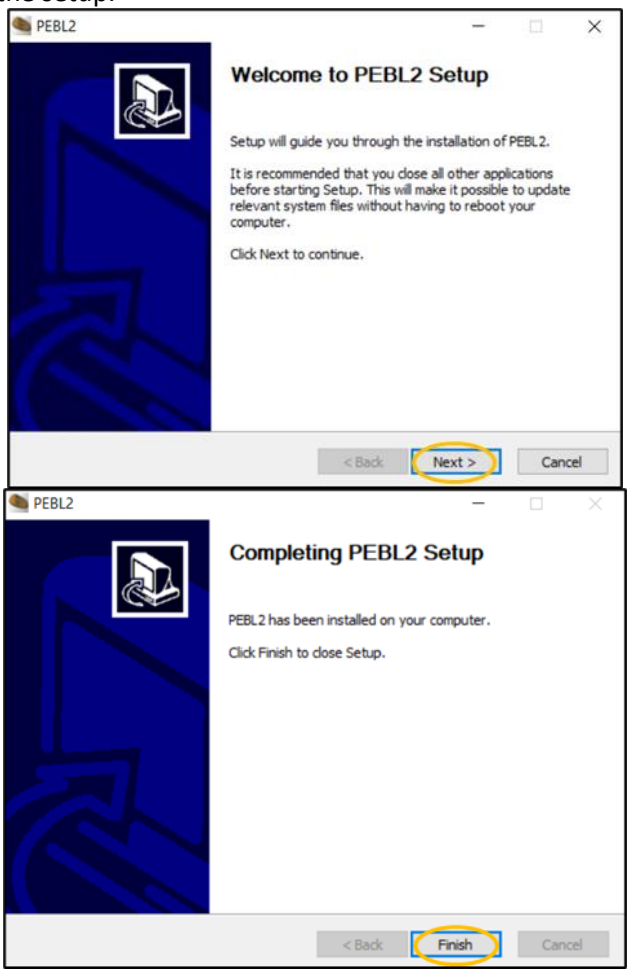
On the next screen, it will show the software beginning to download and the “PEBL_setup.2.1.exe” box should show up at the bottom left of the screen. When the download has finished, click this box and a pop-up will appear asking if you allow the app to make changes. Click “Yes”.



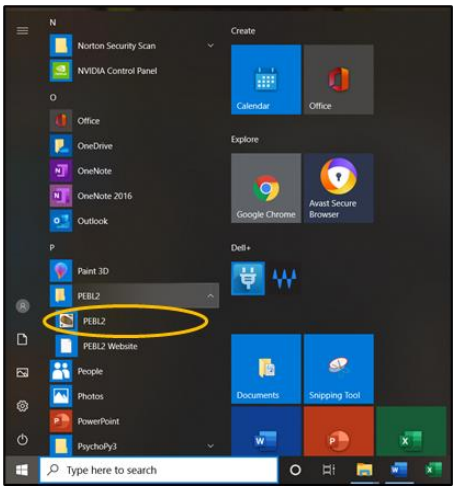
Then a second window will pop-up, asking you to choose a location to install the program. If the default folder is okay, click “Install”.



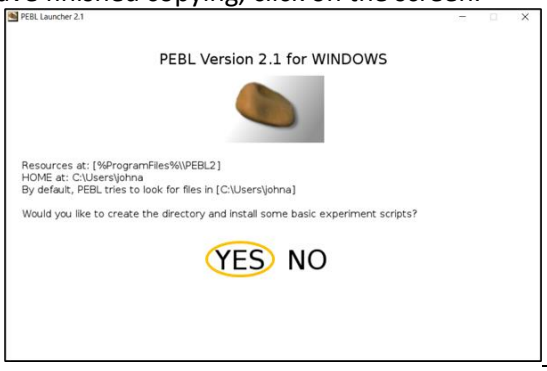
The next window will start the setup process. Click through these steps. Finally, you can click "Finish" to complete the setup.

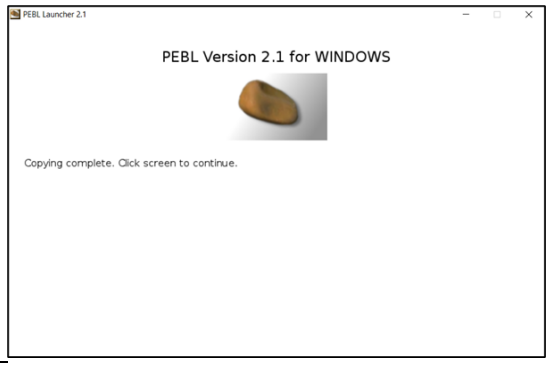


The PEBL software should now show up in your programs list. Open the program.

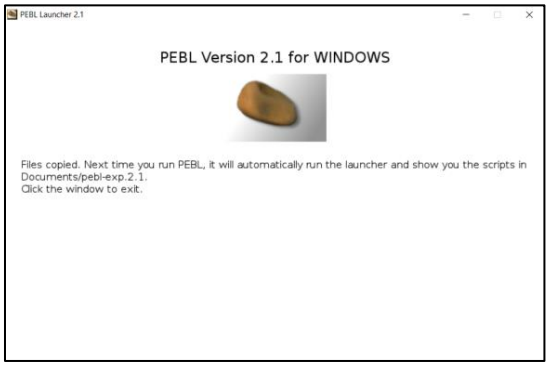


The first time you open it, you will get the window shown below. Click “YES”. When the files have finished copying, click on the screen.



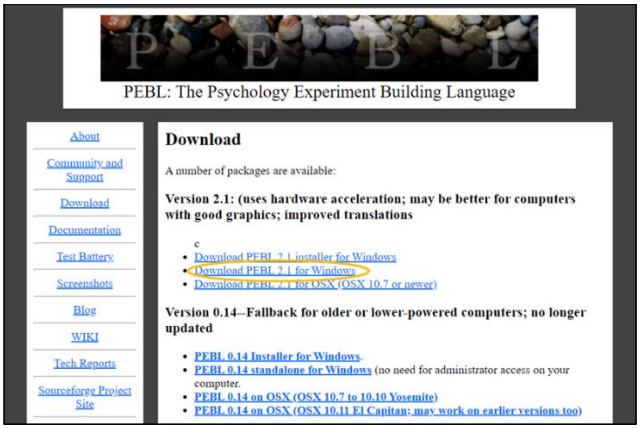


Then on the next window, click to exit.

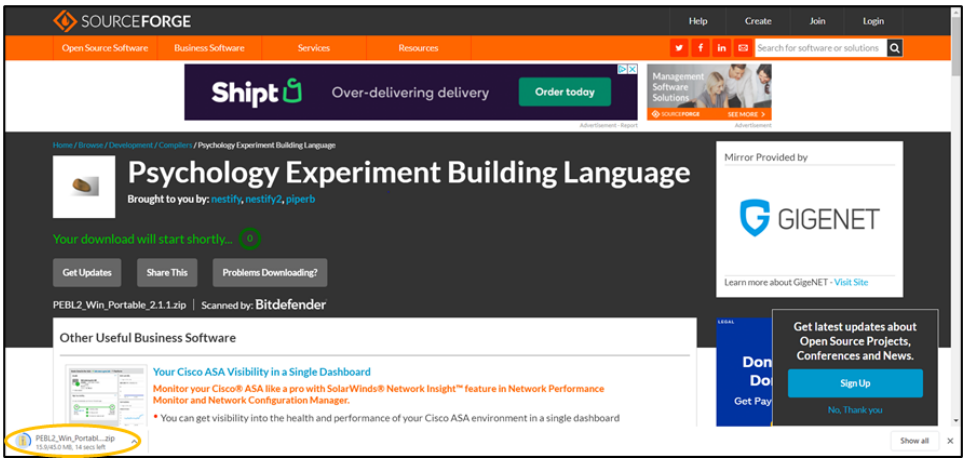


Option 2: Download and extract zip file

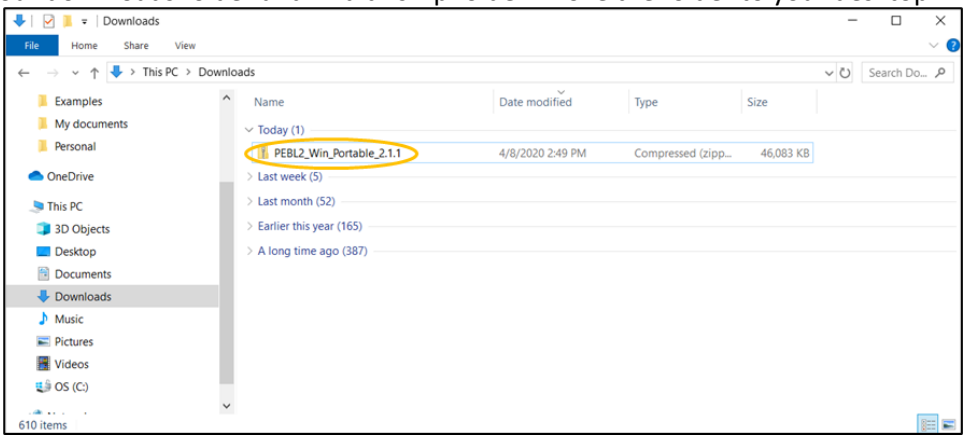
Click “Download PEBL 2.1 for Windows”.



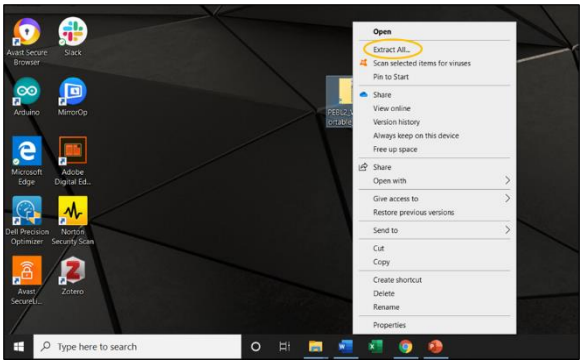
On the next screen, it will show the software beginning to download and the "PEBL2_Win_Portable_2.1.1" zip folder box should show up at the bottom left of the screen. Wait for the folder to download.

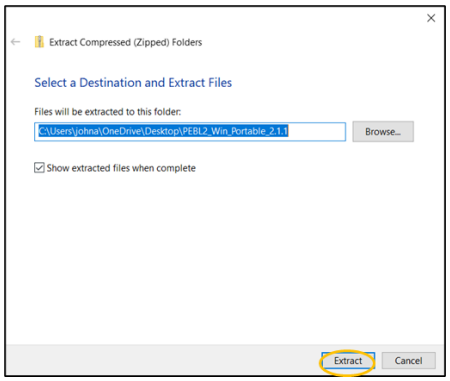


Go to your downloads folder and find this zip folder. Move the folder to your desktop.

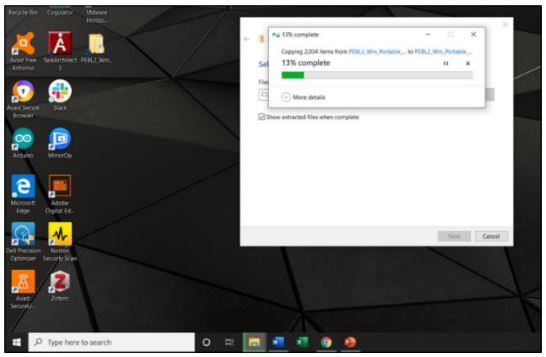


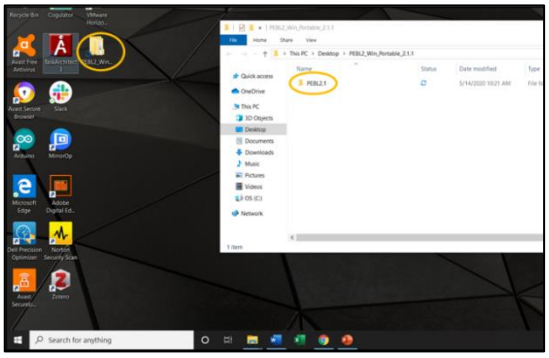
Right click on the folder and "Extract All…". Then in the new window, click "Extract".



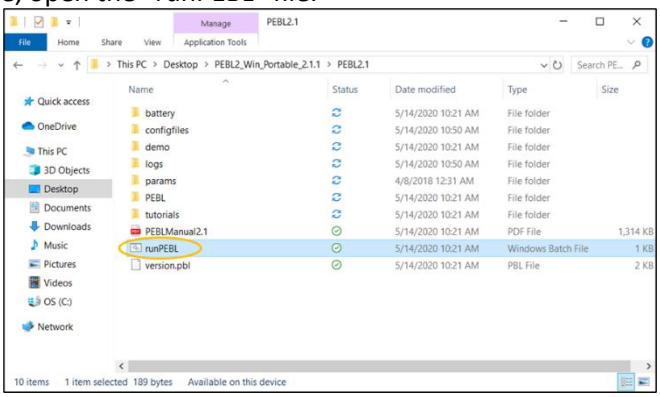


Wait for the files to extract. Then the extracted folder should pop-up (or the icon will show on your desktop). Within the "PEBL_Win_Portable_2.1.1", open the "PEBL2.1" folder.





To open the software, open the "runPEBL" file.



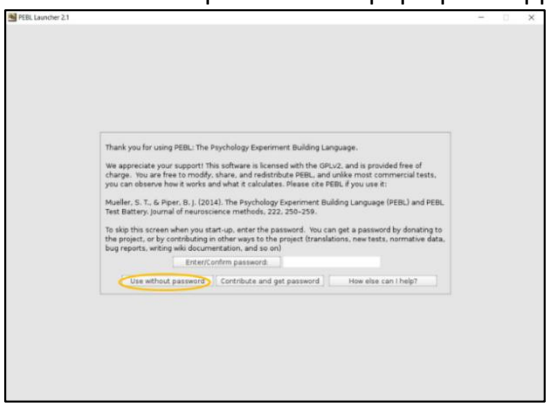
For Mac (OSX) users, there is just one option:

Please watch this video for instructions: https://www.youtube.com/watch?v=SLvmger55ok

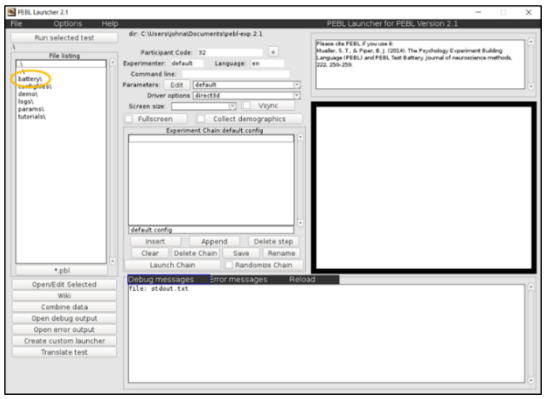
In addition to learning how to download and run the software, pay attention to where the video tells you that your data will be stored (within the "battery" folder). Later you will need to obtain your data and email it to the research team.

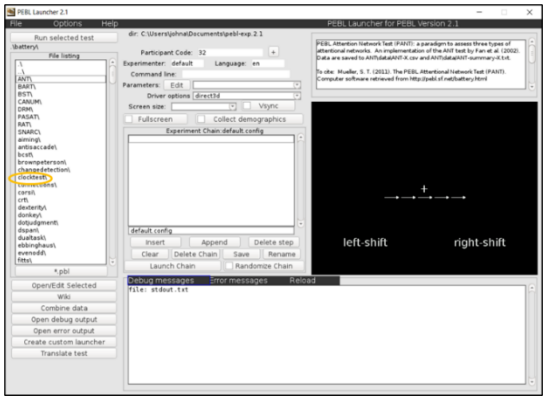
Step 3: Try out the PEBL software and complete the practice session

When you open the PEBL software, it will show a window in which it asks for a password. Just click “Use without password”. A pop-up will appear, and you can just click “OK”.

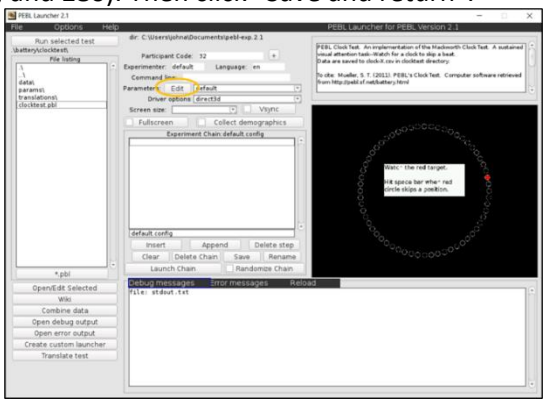


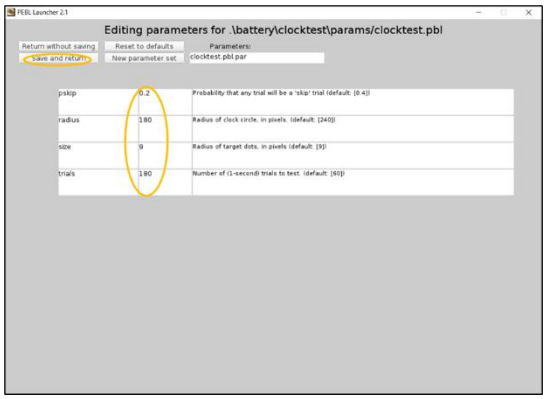
The next window is the main screen. Double-click on “battery\”. Then double-click on “clocktest\”.



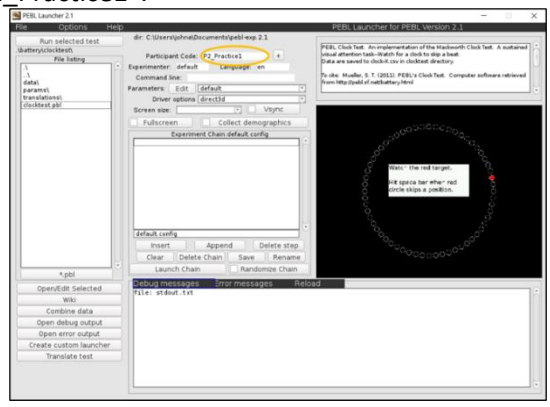


In the next window, click the “Edit” button to change the parameters. In this window, change the numbers (circled in orange) to be the same as those shown in the picture below (**0.2**, **180**, **9**, and **180**). Then click “Save and return”.





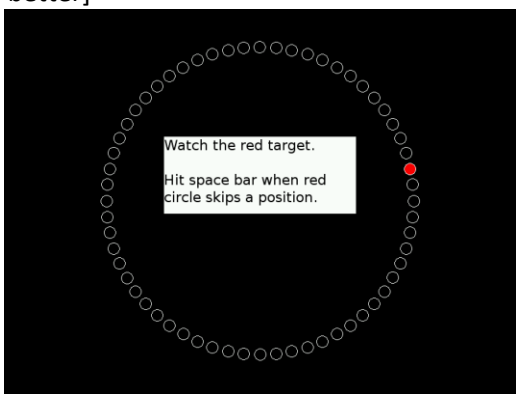
You will now be back at the previous window. In the “Participant Code” box, type in “**P#_Practice1**” with your participant number in place of the “#”. For example, if you are participant 2, type in “P2_Practice1”.



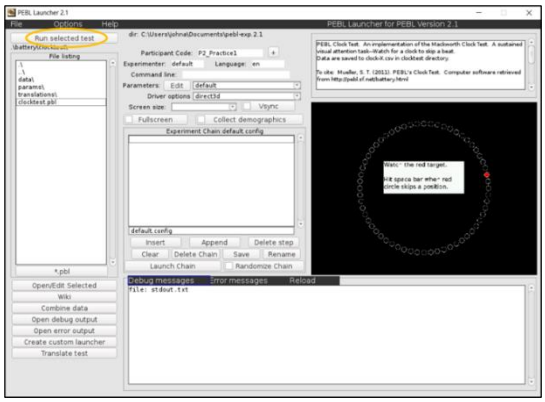
Everything is now setup for you to complete a practice session of the task. Before you begin, here is an explanation of how to perform the task.

You will be watching a screen like the one shown below. The red target (dot) will move from one position (white circle) to the next every second, similar to how the second hand moves around a clock. Sometimes the red dot will skip a circle. When this happens, you should press the space bar as quickly as you can. If the red dot does not skip a circle, then you should *not* press the space bar (do not do anything). Your performance will be graded on the following measures:

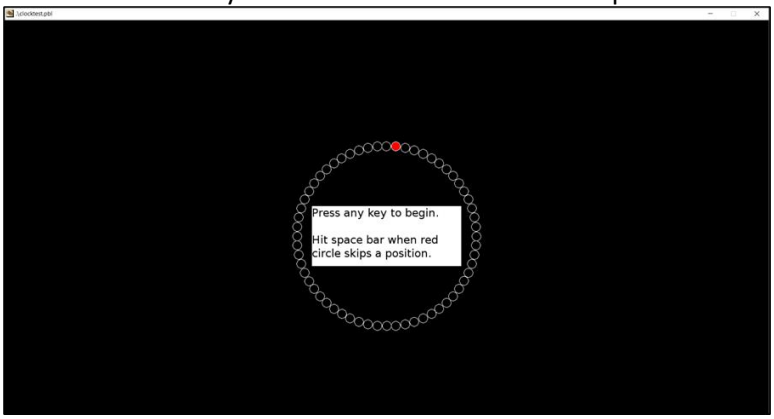
Detection rate: Percentage of skips you detect (by pressing the space bar) [higher is better]
Reaction time: The time it takes you to press the space bar when a skip occurs [lower (quicker) is better]
False alarms: The number of times you press the space bar when a skip has not occurred [fewer is better]



Now you will complete a 3-minute practice session. Click “Run selected test”.



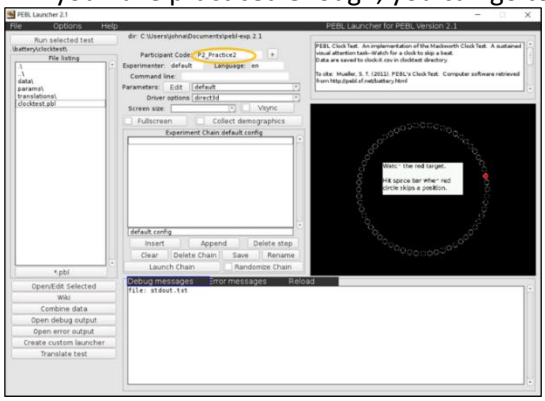
This window will pop-up. As it says in the center, you can press any key to begin. After 3 minutes, the task will automatically end. Note: You are not able to pause the task once it starts.



When the task ends, a screen like this will pop-up which shows your results. In the example below, there were 22 skips, 19 of which were detected, so this person had a detection rate of about 86% (19/22 = 0.863) and 0 false alarms. This is a fairly good performance.

If your detection rate was less than 85%, and/or if you had several false alarms, we recommend that you re-do the practice session and improve your score before continuing. Just update the

"Participant Code" box to be "**P#_Practice2**" for your 2nd practice session and so forth (see picture below). If you did not understand the directions, you can re-read them before retrying the practice. When you think you have practiced enough, you can go to the next step.



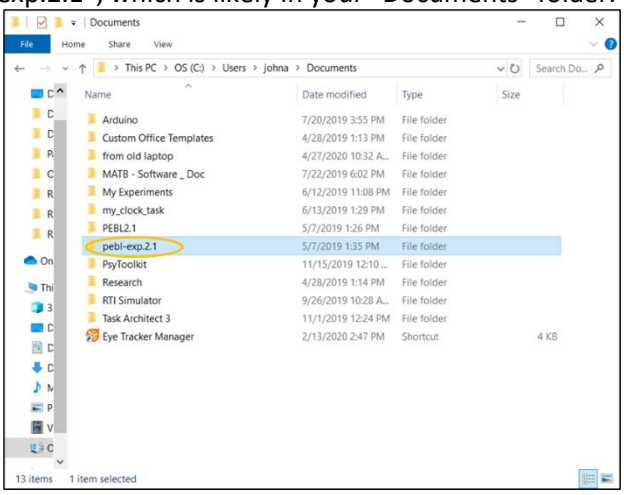
Step 4: Find and email practice data

The PEBL software automatically saves your task data to a folder on your computer.

The location of the data will depend on which option you used to download the software.

Folder location for Option 1:

Find the folder "pebl-exp.2.1", which is likely in your "Documents" folder.



When you find the folder, open it, and follow the following folder path:

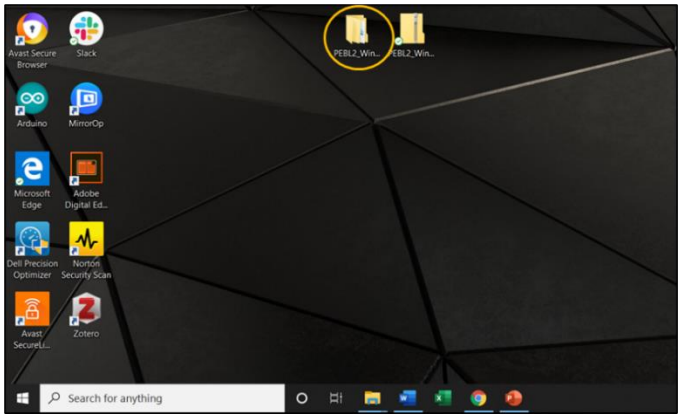
battery

clocktest

data

Folder location for Option 2:

Find the folder "PEBL2_Win_Portable_2.1.1", which is likely on your desktop.



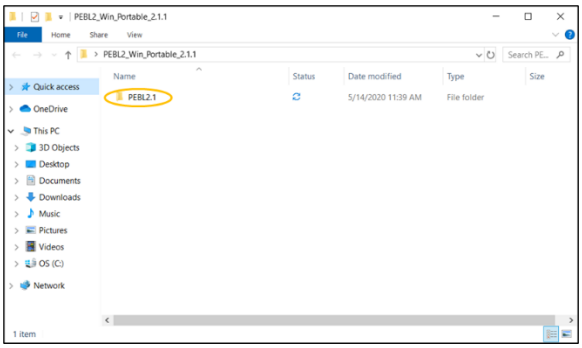
In this folder follow the following folder path:

PEBL2.1

battery

clocktest

data



Folder location for <u>Mac (OSX) Option:</u>

Please watch this video for instructions: https://www.youtube.com/watch?v=SLvmger55ok

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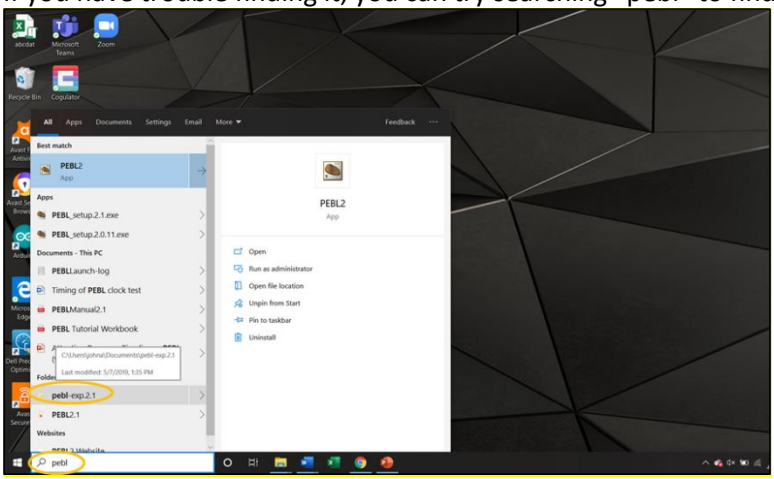
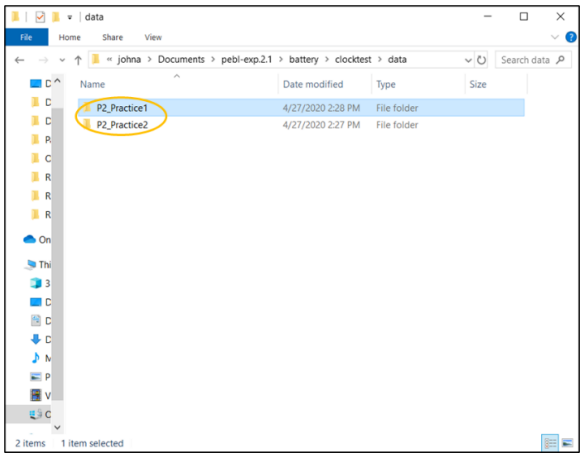
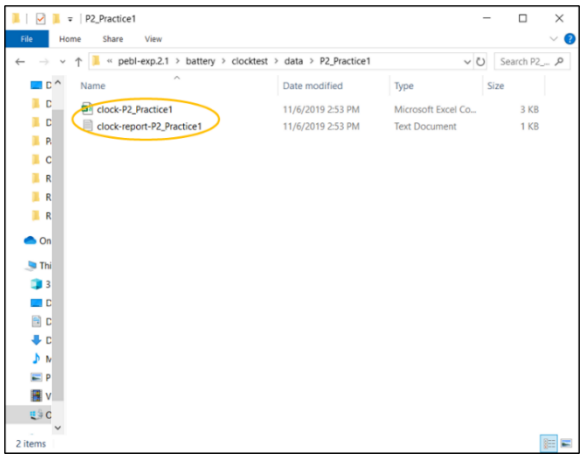
For any option, if you have trouble finding it, you can try searching “pebl” to find it.



Once you get in the “data” folder, you should see one or more folders which contain your practice data. So, if you had two practice sessions, you should have two folders (as in the picture below).

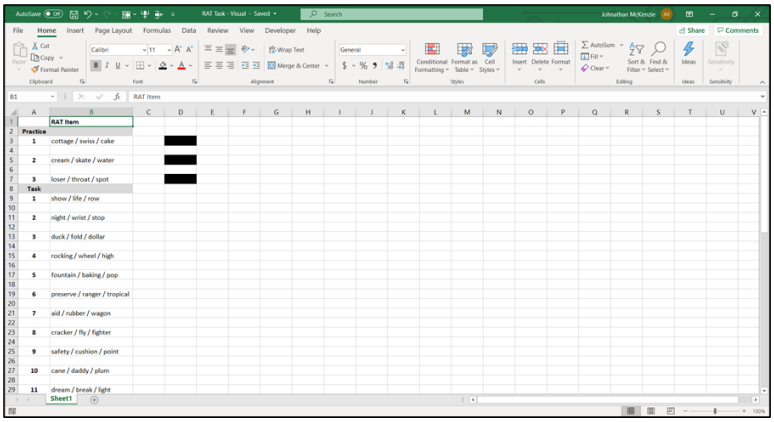


Opening one of the folders, you should see two files. For *each* folder, these files need to be emailed to the research team (tamu.attention.study@gmail.com). You can go ahead and email your practice files or wait and email all your files together after you complete the full task session.



Step 5: Try out the other task and complete the practice session

The other task you may complete during the experiment is the Remote Associates Test (RAT). Open the Excel file “RAT Task - Visual”. The spreadsheet is divided into two sections, the first for practicing.



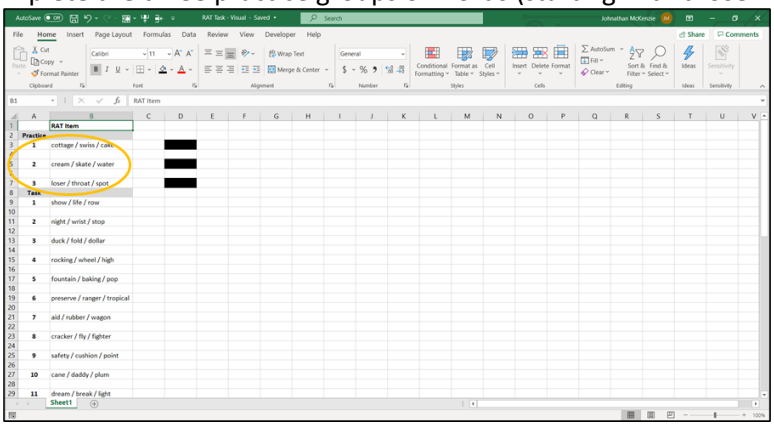
Instructions: You will read the three words in column B and then think of a fourth word that is related to each of the first three words.

Here is an example (not shown on spreadsheet):

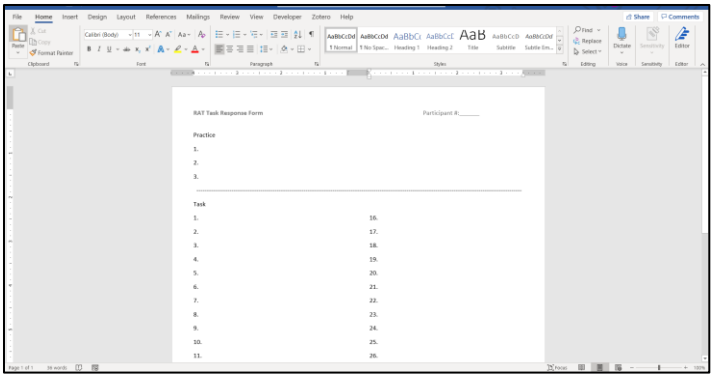
envy / golf / beans Correct answer: green

Although envy, golf, and beans do not really relate to each other, they each relate to green in a way. “Green with envy” is a common phrase to describe jealousy. One area of a golf course is the “green”. And then “green beans” are a type of vegetable. As you can see, the words can relate to each other in different ways.

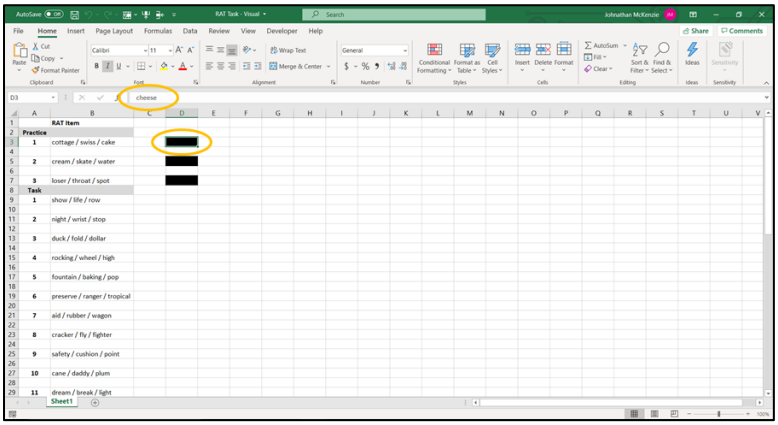
Now you can complete the three practice groups of words (starting with those in cell B3).



Read the words and then take your time to try to think of a word that relates to them all. Next type your answer in the document “RAT Task Response Form” (see below). You can guess or leave it blank if you do not think you have an answer.



When you are ready to know the answer, click on the blacked-out cell to the right of the words and look in the formula bar to see the text hidden behind the black-out.



Then try to complete <u>only the other two</u> practice groups of words. When you have finished the practice groups, *save* the "RAT Task Response Form".
<u>Do not</u> complete the groups of words in the "Task" section at this time.

Summary of Steps:

Step 1: Sign the Consent Form
Step 2: Download and setup the needed software
Step 3: Try out the PEBL software and complete the practice session
Step 4: Find and email practice data
Step 5: Try out the other task and complete the practice session

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If you have completed the above steps, then you have finished the pre-experiment. When you are ready, you can go to the next document "Experiment Instructions".

APPENDIX C

PRE-EXPERIMENT (REMOTE) INSTRUCTIONS FOR GROUP 5

Pre-Experiment Steps

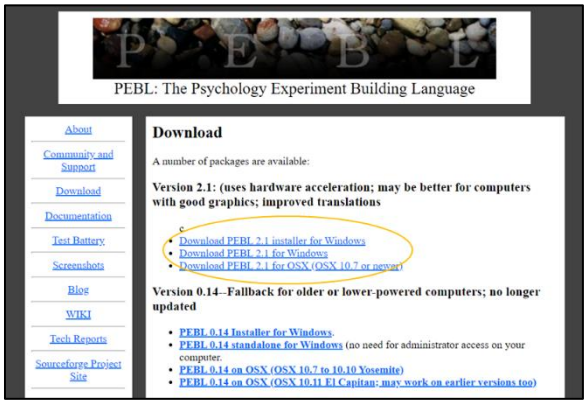
Thank you for agreeing to participate in this study. This document will guide you through the steps of preparing for the experiment.

Step 1: Sign the Consent Form
If you have not done so already, please read and sign the consent form before continuing: https://tamu.qualtrics.com/jfe/form/SV_37V2eZlJgvYUDMW

Step 2: Download and setup the needed software
This is a free software created by researchers to study human task performance. It is used by several research teams at Texas A&M and other universities.

> We understand that you may be hesitant to download an unknown software. Because it was developed to be freely used for research purposes, it does lack the professional appearance of software created for purchase. However, it has been used by several research universities as documented in the journal article (cited 558 times according to Google Scholar) attached in the last email:
>
> "The Psychology Experiment Building Language (PEBL) and PEBL Test Battery"
>
> If you still do not feel comfortable downloading the software, please contact johnathan.mckenzie@tamu.edu and tferris@tamu.edu before continuing.

To download the software, go to http://pebl.sourceforge.net/download.html and select the download option needed for your computer (circled in orange in the picture below).

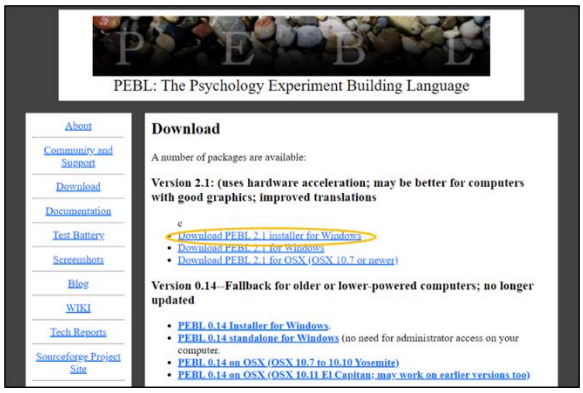


For Windows users, there are two options:

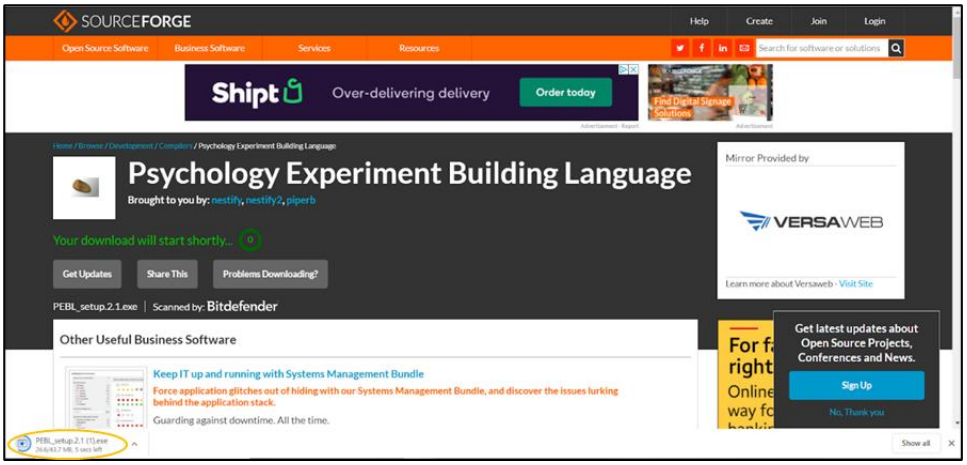
> (This video (https://www.youtube.com/watch?v=YyhARjcYSew) also explains the installation process, but it is not as concise as the directions given below.)

Option 1: Use the Windows installer

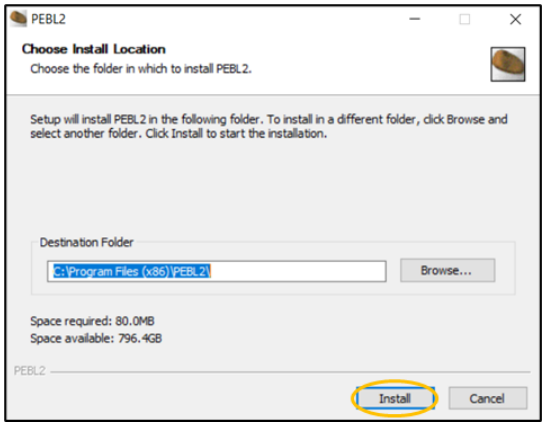
Click “Download PEBL 2.1 installer for Windows”.



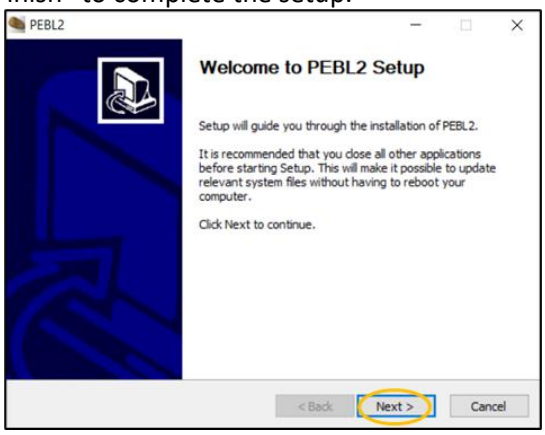
On the next screen, it will show the software beginning to download and the “PEBL_setup.2.1.exe” box should show up at the bottom left of the screen. When the download has finished, click this box and a pop-up will appear asking if you allow the app to make changes. Click “Yes”.

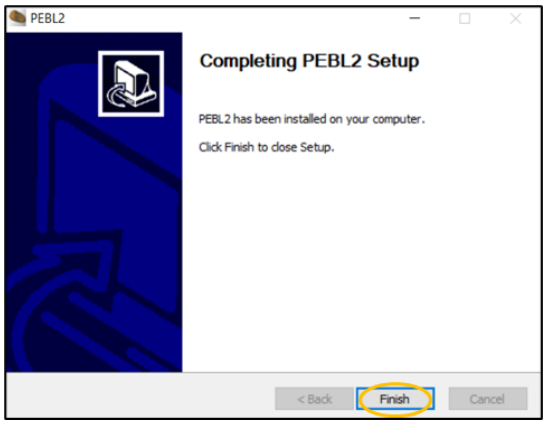


Then a second window will pop-up, asking you to choose a location to install the program. If the default folder is okay, click “Install”.

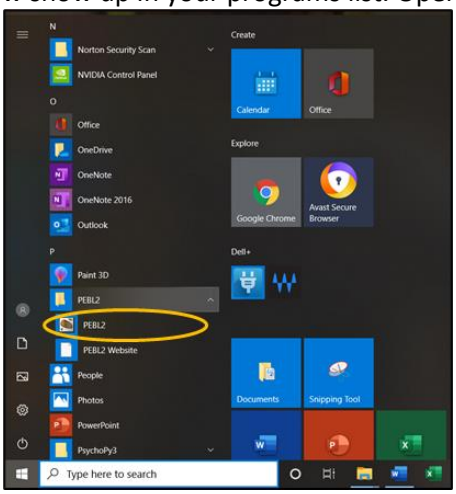


The next window will start the setup process. Click through these steps. Finally, you can click "Finish" to complete the setup.

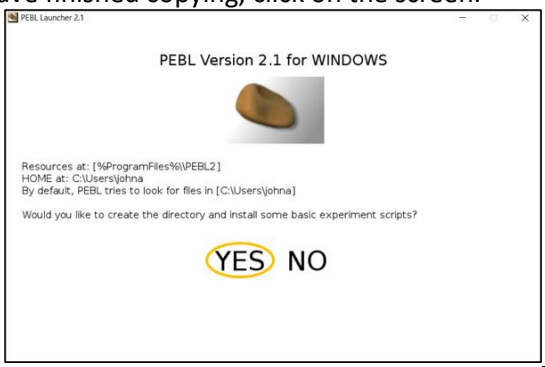


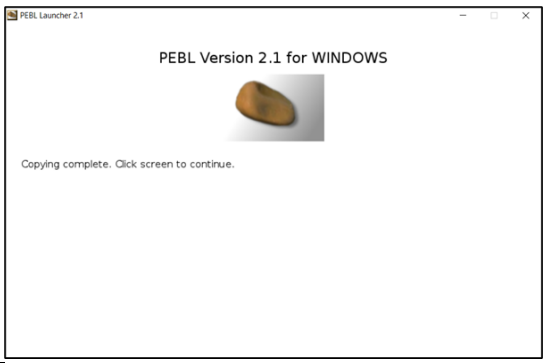


The PEBL software should now show up in your programs list. Open the program.

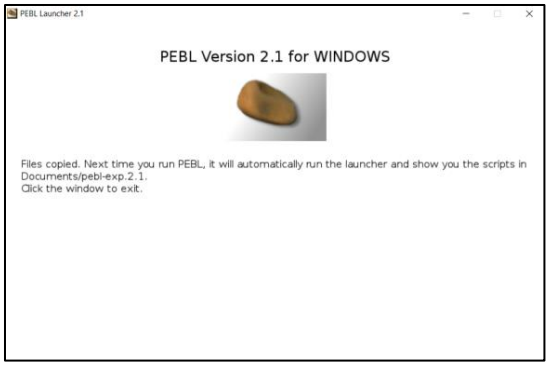


The first time you open it, you will get the window shown below. Click "YES". When the files have finished copying, click on the screen.



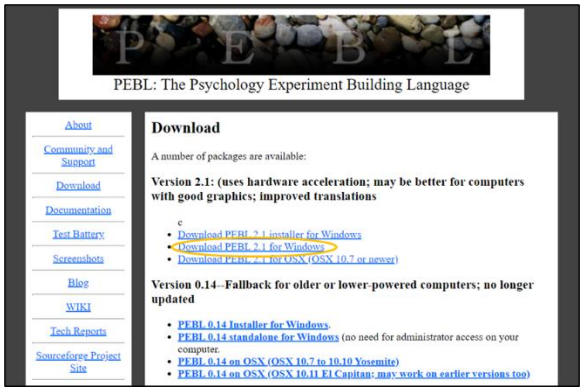


Then on the next window, click to exit.

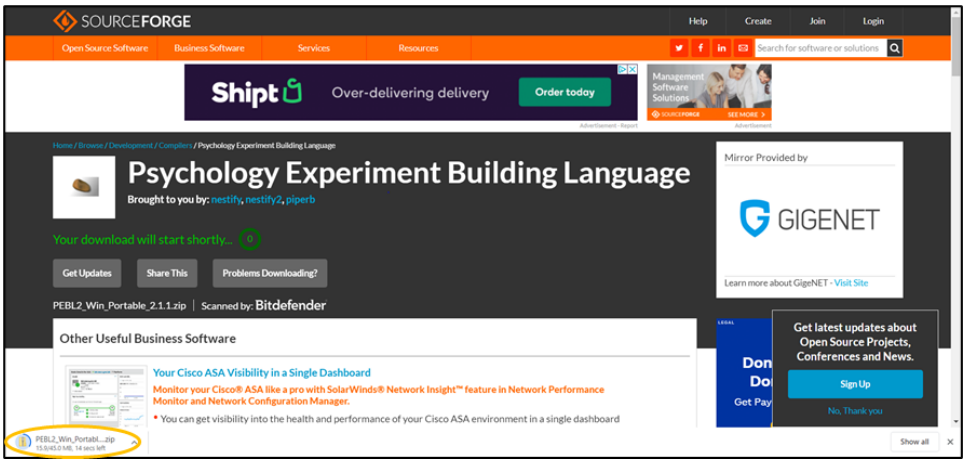


Option 2: Download and extract zip file

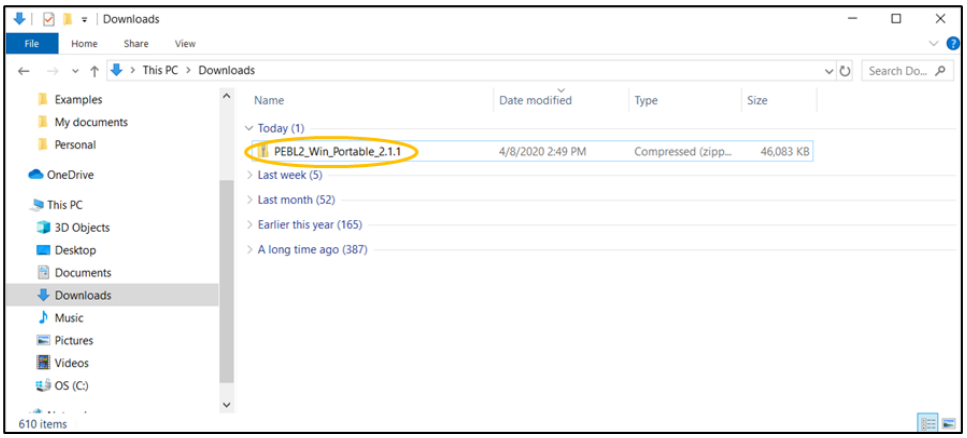
Click “Download PEBL 2.1 for Windows”.



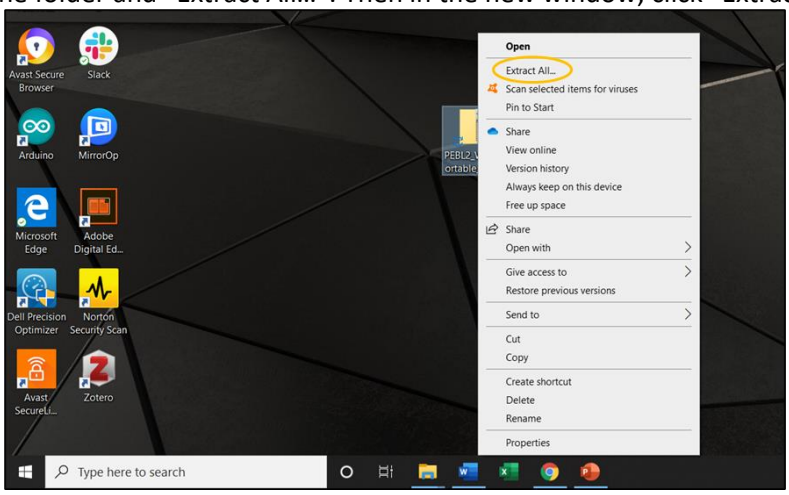
On the next screen, it will show the software beginning to download and the “PEBL2_Win_Portable_2.1.1” zip folder box should show up at the bottom left of the screen. Wait for the folder to download.

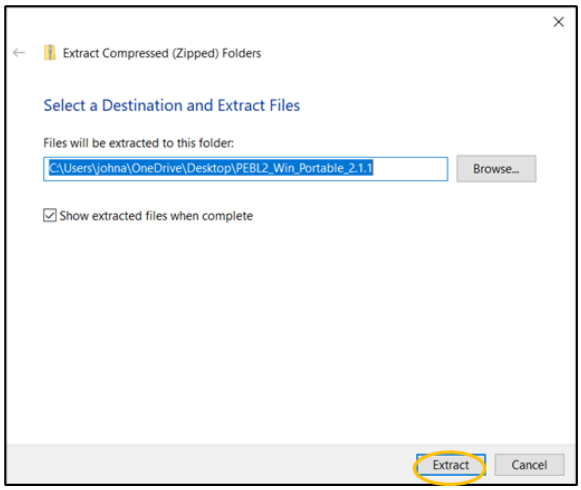


Go to your downloads folder and find this zip folder. Move the folder to your desktop.

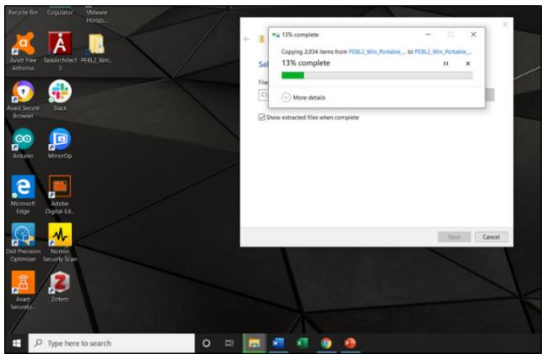


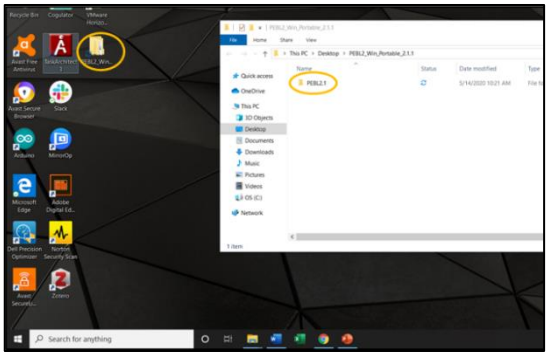
Right click on the folder and “Extract All…”. Then in the new window, click “Extract”.



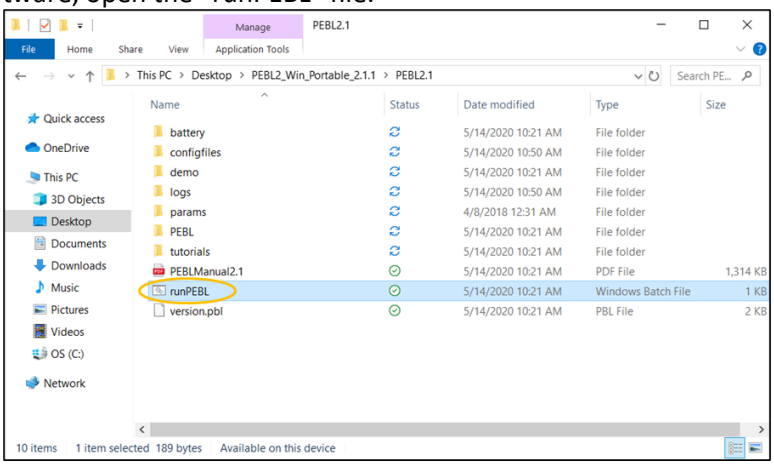


Wait for the files to extract. Then the extracted folder should pop-up (or the icon will show on your desktop). Within the “PEBL_Win_Portable_2.1.1”, open the “PEBL2.1” folder.





To open the software, open the “runPEBL” file.



<u>For Mac (OSX) users, there is just one option:</u>

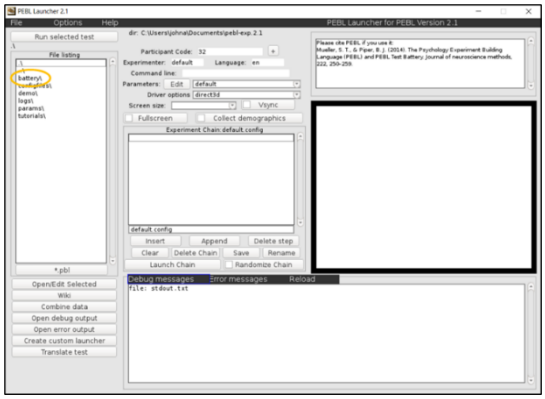
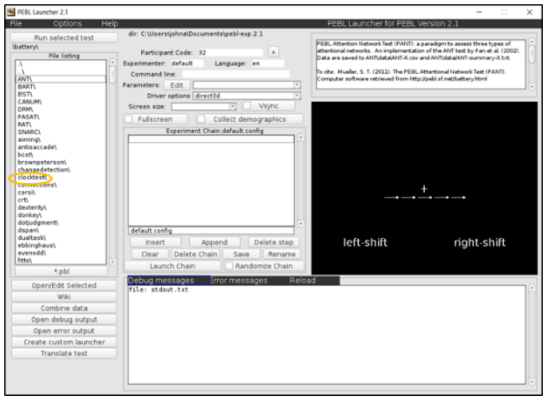
Please watch this video for instructions: https://www.youtube.com/watch?v=SLvmger55ok

In addition to learning how to download and run the software, pay attention to where the video tells you that your data will be stored (within the “battery” folder). Later you will need to obtain your data and email it to the research team.

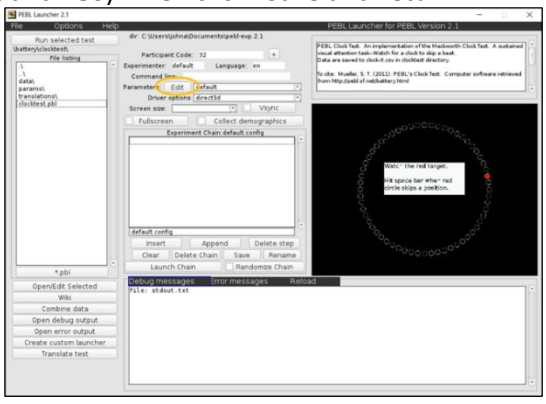
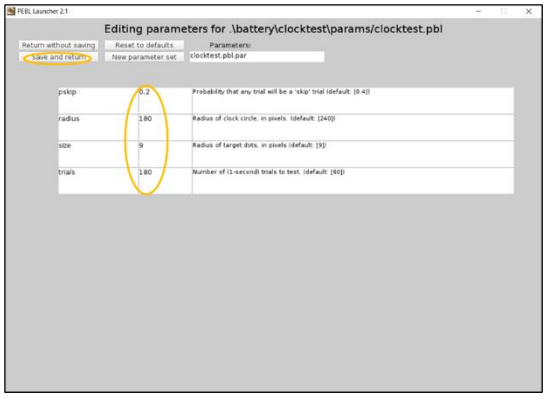
Step 3: Try out the PEBL software and complete the practice session

When you open the PEBL software, it will show a window in which it asks for a password. Just click “Use without password”. A pop-up will appear, and you can just click “OK”.

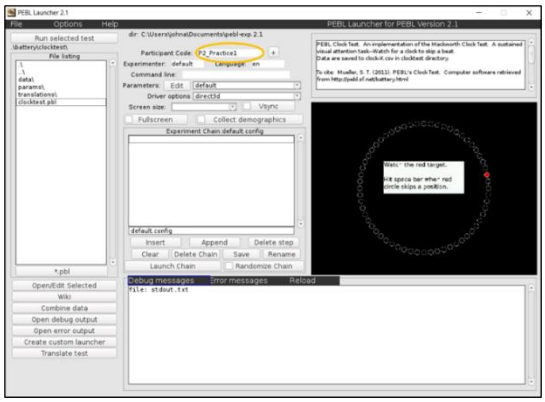
The next window is the main screen. Double-click on “battery\”. Then double-click on “clocktest\”.

In the next window, click the “Edit” button to change the parameters. In this window, change the numbers (circled in orange) to be the same as those shown in the picture below (**0.2**, **180**, **9**, and **180**). Then click “Save and return”.

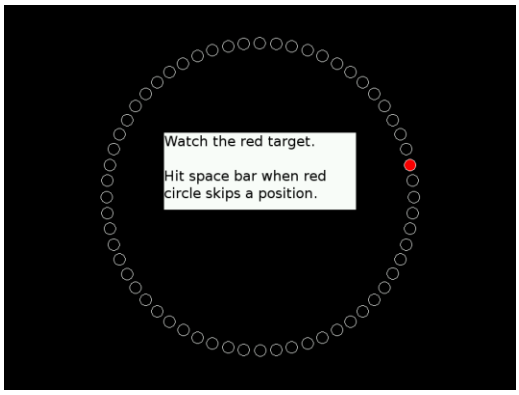
You will now be back at the previous window. In the “Participant Code” box, type in “**P#_Practice1**” with your participant number in place of the “#”. For example, if you are participant 2, type in “P2_Practice1”.



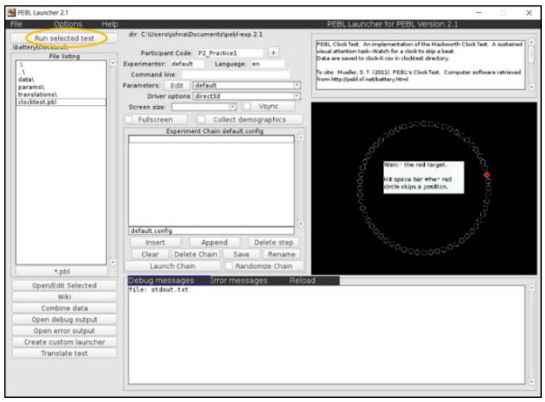
Everything is now setup for you to complete a practice session of the task. Before you begin, here is an explanation of how to perform the task.

You will be watching a screen like the one shown below. The red target (dot) will move from one position (white circle) to the next every second, similar to how the second hand moves around a clock. Sometimes the red dot will skip a circle. When this happens, you should press the space bar as quickly as you can. If the red dot does not skip a circle, then you should *not* press the space bar (do not do anything). Your performance will be graded on the following measures:

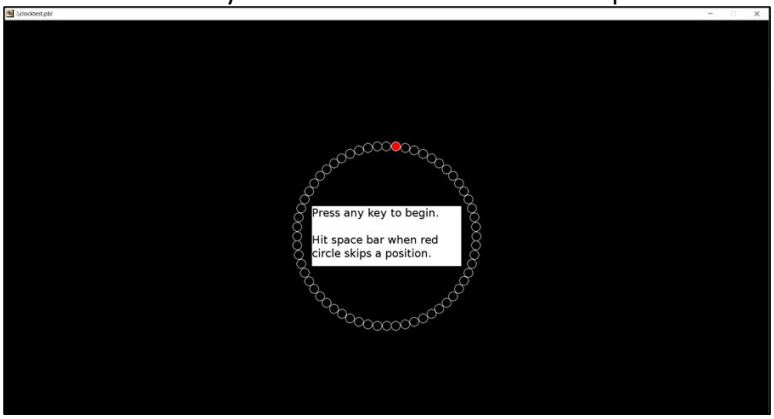
Detection rate: Percentage of skips you detect (by pressing the space bar) [higher is better]
Reaction time: The time it takes you to press the space bar when a skip occurs [lower (quicker) is better]
False alarms: The number of times you press the space bar when a skip has not occurred [fewer is better]



Now you will complete a 3-minute practice session. Click “Run selected test”.



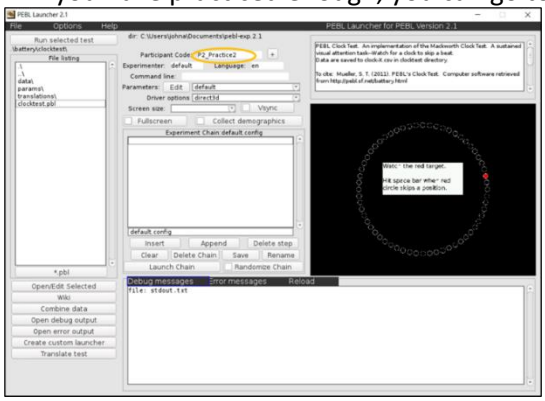
This window will pop-up. As it says in the center, you can press any key to begin. After 3 minutes, the task will automatically end. Note: You are not able to pause the task once it starts.



When the task ends, a screen like this will pop-up which shows your results. In the example below, there were 22 skips, 19 of which were detected, so this person had a detection rate of about 86% (19/22 = 0.863) and 0 false alarms. This is a fairly good performance.

If your detection rate was less than 85%, and/or if you had several false alarms, we recommend that you re-do the practice session and improve your score before continuing. Just update the

"Participant Code" box to be "**P#_Practice2**" for your 2nd practice session and so forth (see picture below). If you did not understand the directions, you can re-read them before retrying the practice. When you think you have practiced enough, you can go to the next step.



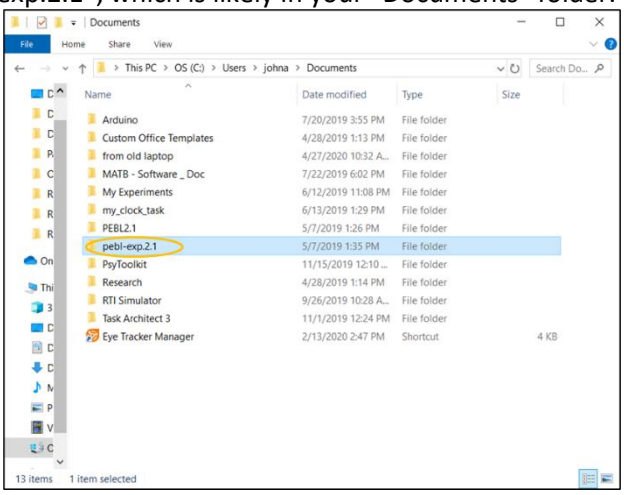
Step 4: Find and email practice data

The PEBL software automatically saves your task data to a folder on your computer.

The location of the data will depend on which option you used to download the software.

Folder location for Option 1:

Find the folder "pebl-exp.2.1", which is likely in your "Documents" folder.



When you find the folder, open it, and follow the following folder path:

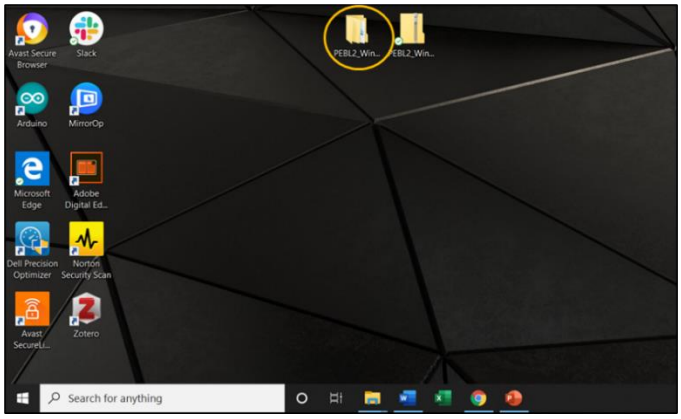
battery

clocktest

data

Folder location for Option 2:

Find the folder "PEBL2_Win_Portable_2.1.1", which is likely on your desktop.



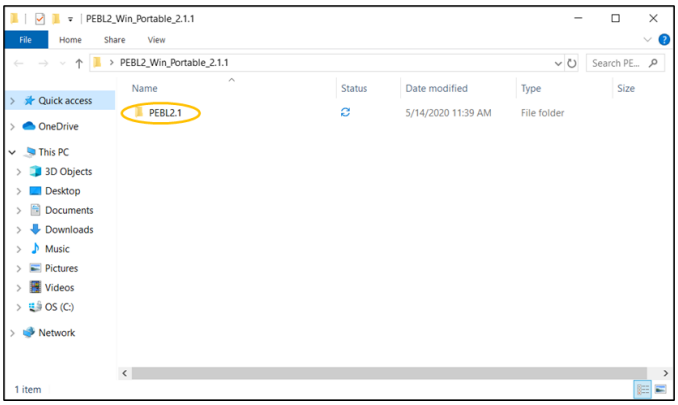
In this folder follow the following folder path:

PEBL2.1

battery

clocktest

data



Folder location for Mac (OSX) Option:

Please watch this video for instructions: https://www.youtube.com/watch?v=SLvmger55ok

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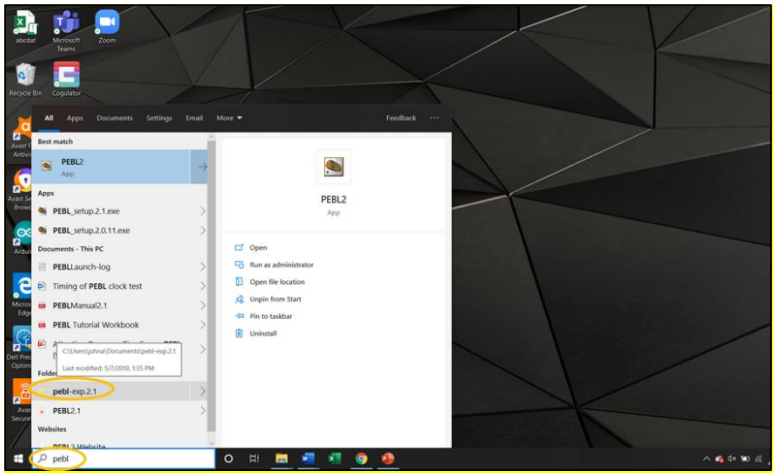
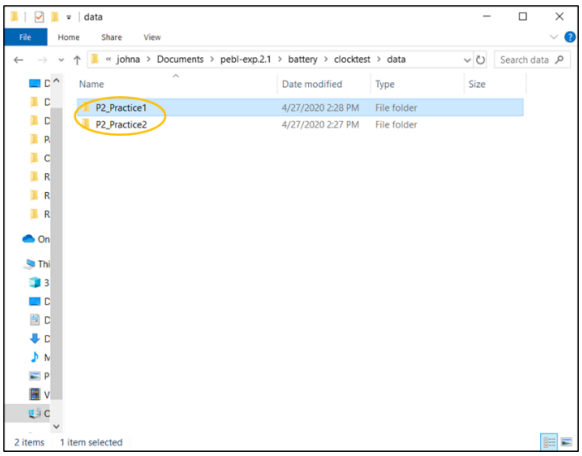
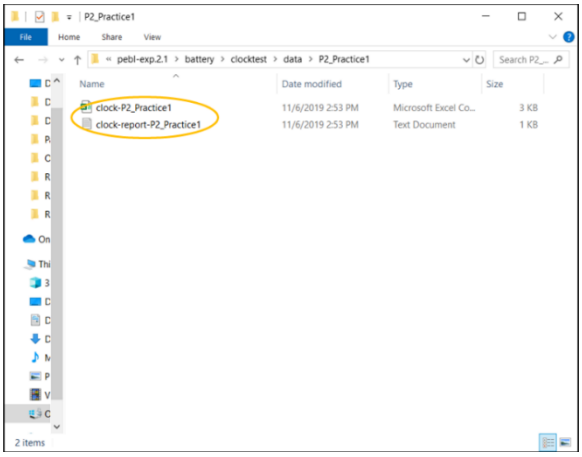
For any option, if you have trouble finding it, you can try searching “pebl” to find it.



Once you get in the “data” folder, you should see one or more folders which contain your practice data. So, if you had two practice sessions, you should have two folders (as in the picture below).

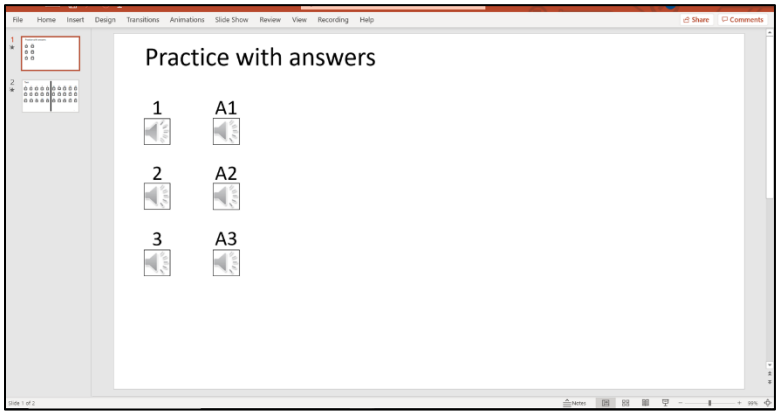


Opening one of the folders, you should see two files. For *each* folder, these files need to be emailed to the research team (tamu.attention.study@gmail.com). You can go ahead and email your practice files or wait and email all your files together after you complete the full task session.



Step 5: Try out the other task and complete the practice session

The other task you may complete during the experiment is the Multi-Adjacent State Task (MAST). Open the PowerPoint file "MAST - Auditory". The file will contain two slides, the first for practicing.



Instructions: You will click a play button and listen to the recording of three state names. Next, think of a fourth state that is adjacent to (shares a border with) each of the three given states. (The three given states may or may not share a border with each other, but they each share a border with the fourth state.)

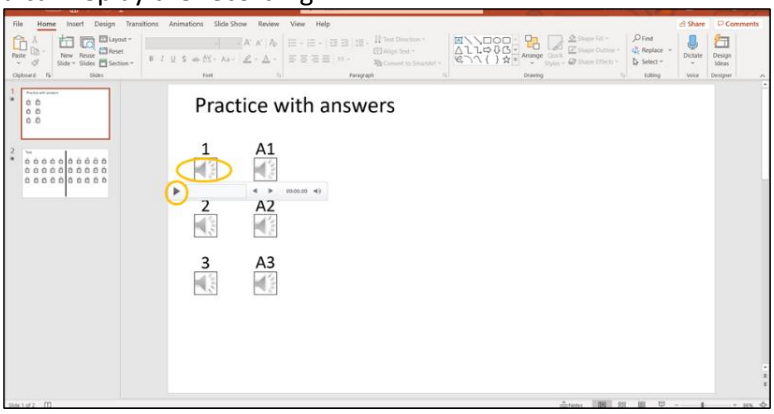
Here is an example:

New Mexico / Oklahoma / Louisiana Correct answer: Texas

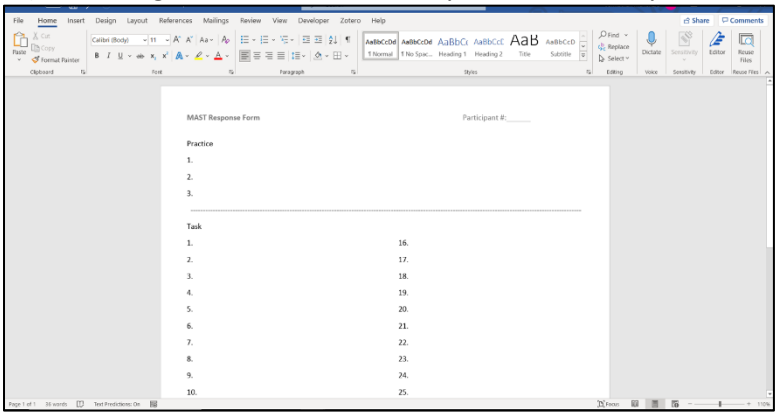
Although New Mexico, Oklahoma, and Louisiana do not all share borders with each other, they each share a border with Texas. There is no state other than Texas which shares a border with all three of these states. Another state, Arkansas, also shares a border with Texas, but only three states adjacent to Texas were given.

The map below is shown to explain this example. However, when you complete the task, you **should not** be looking at a map (neither labeled nor unlabeled).

Now you can complete the practice groups of states. On the first slide, there are three practice recordings and their corresponding answers. Under “1”, hover your cursor over the speaker symbol and then a play button will appear. Click the play button to listen to the recording. If you need to, you can replay the recording.



After you have listened to the state names, take your time to try to think of the state which shares a border with each of these. Then type your answer in the document “MAST Response Form” (see below). You can guess or leave it blank if you do not think you have an answer.



When you are ready to hear the answer, play the recording under “A1” on the first slide. Then try to complete only the other two practice recordings. When you have finished the practice recordings, *save* the “MAST Response Form”.
Do not complete the other recordings (on the second slide) at this time.

Summary of Steps:

Step 1: Sign the Consent Form
Step 2: Download and setup the needed software
Step 3: Try out the PEBL software and complete the practice session
Step 4: Find and email practice data
Step 5: Try out the other task and complete the practice session

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If you have completed the above steps, then you have finished the pre-experiment. When you are ready, you can go to the next document “Experiment Instructions”.

APPENDIX D

PRE-EXPERIMENT INSTRUCTIONS FOR GROUP 6

Pre-Experiment Steps

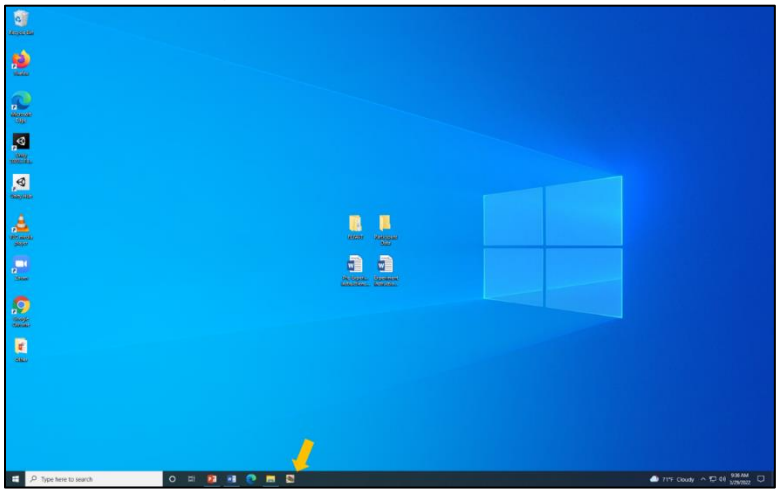
Thank you for agreeing to participate in this study. This document will guide you through the steps of preparing for the experiment.

Step 1: Sign the Consent Form

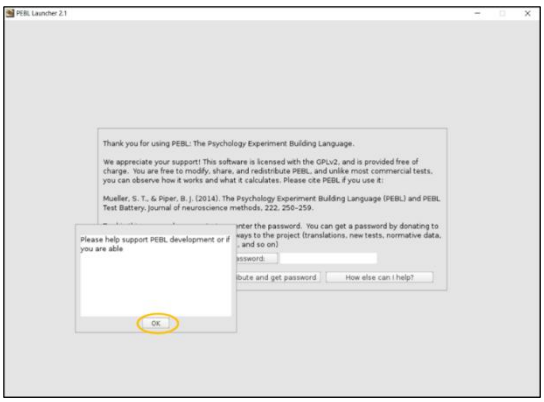
If you have not done so already, please read and sign the consent form before continuing: https://tamu.qualtrics.com/jfe/form/SV_37V2eZlJgvYUDMW

Step 2: Try out the PEBL software and complete the practice session

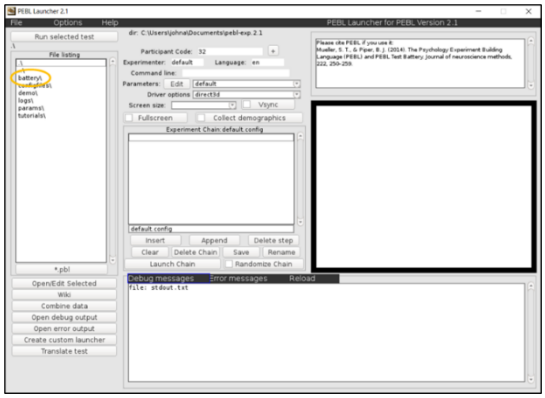
Find and open the PEBL software (icon located on the taskbar at the bottom of the screen).

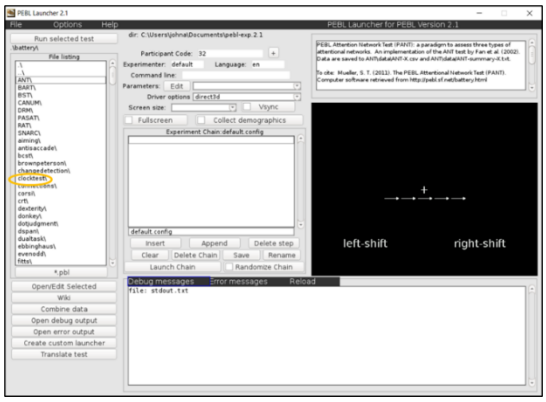


When you open the PEBL software, it will show a window in which it asks for a password. Just click “Use without password”. A pop-up will appear, and you can just click “OK”.

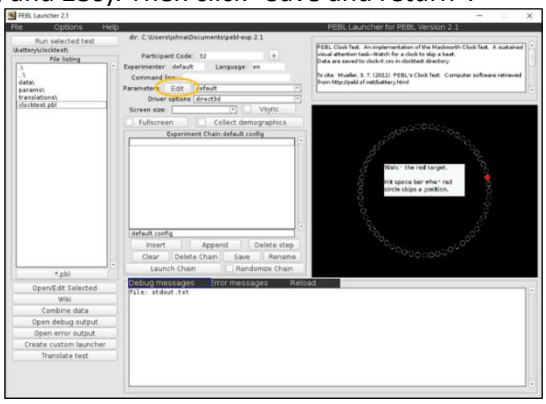


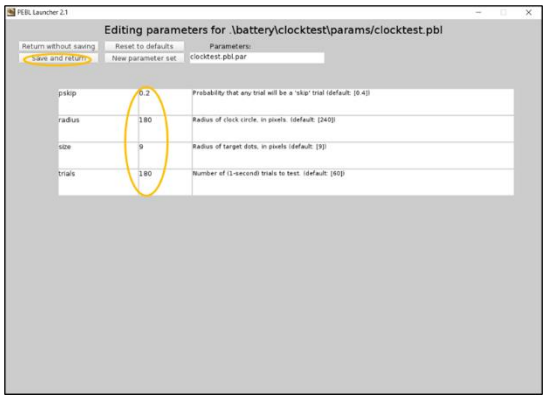
The next window is the main screen. Double-click on “battery\”. Then double-click on “clocktest\”.



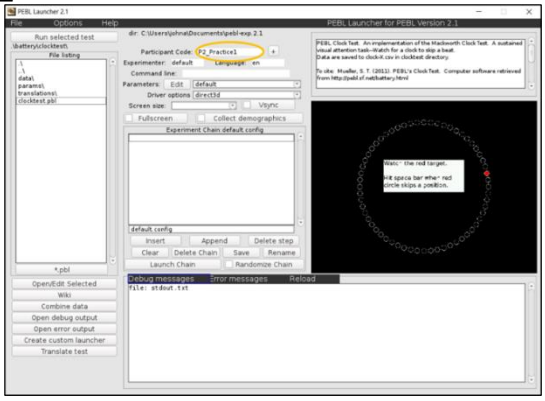


In the next window, click the “Edit” button to change the parameters. In this window, change the numbers (circled in orange) to be the same as those shown in the picture below (**0.2**, **180**, **9**, and **180**). Then click “Save and return”.





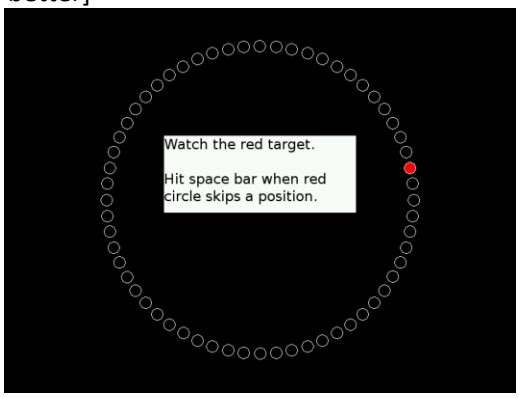
You will now be back at the previous window. In the “Participant Code” box, type in “**P#_Practice1**” with your participant number in place of the “#”. For example, if you are participant 2, type in “P2_Practice1”.



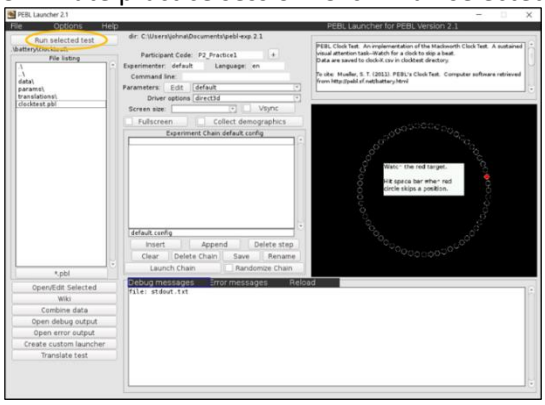
Everything is now setup for you to complete a practice session of the task. Before you begin, here is an explanation of how to perform the task.

You will be watching a screen like the one shown below. The red target (dot) will move from one position (white circle) to the next every second, similar to how the second hand moves around a clock. Sometimes the red dot will skip a circle. When this happens, you should press the space bar as quickly as you can. If the red dot does not skip a circle, then you should *not* press the space bar (do not do anything). Your performance will be graded on the following measures:

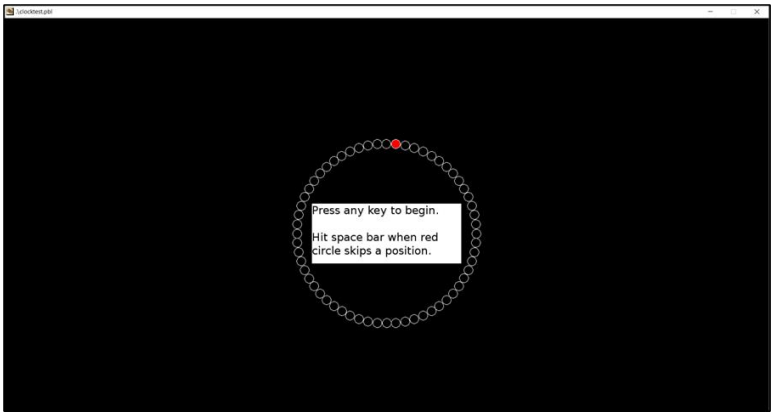
Detection rate: Percentage of skips you detect (by pressing the space bar) [higher is better]
Reaction time: The time it takes you to press the space bar when a skip occurs [lower (quicker) is better]
False alarms: The number of times you press the space bar when a skip has not occurred [fewer is better]



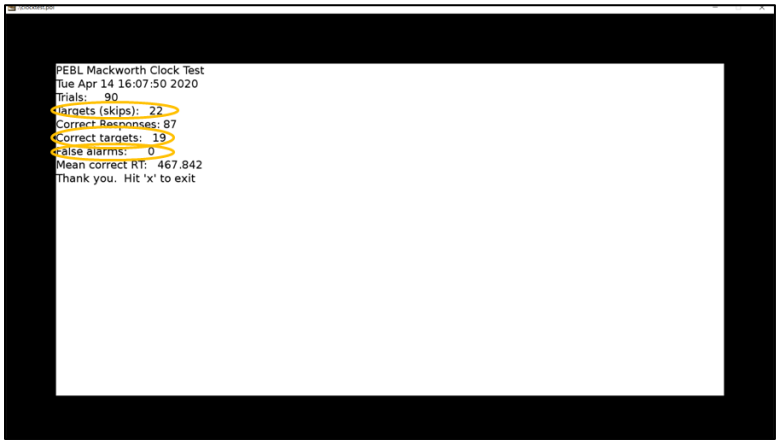
Now you will complete a 3-minute practice session. Click “Run selected test”.



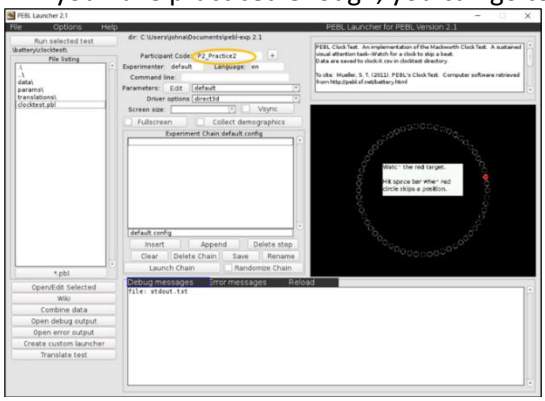
This window will pop-up. As it says in the center, you can press any key to begin. After 3 minutes, the task will automatically end. Note: You are not able to pause the task once it starts.



When the task ends, a screen (like the one below) will pop-up which shows your results. In the example below, there were 22 skips, 19 of which were detected, so this person had a detection rate of about 86% (19/22 = 0.863) and 0 false alarms. This is a fairly good performance.



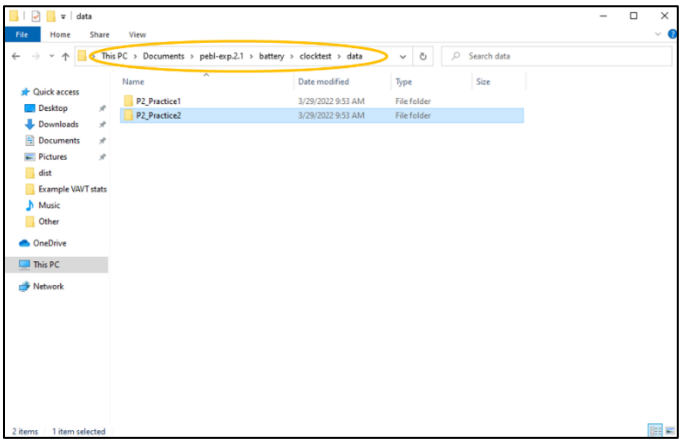
If your detection rate was less than 85%, and/or if you had several false alarms, we recommend that you re-do the practice session and improve your score before continuing. Just update the "Participant Code" box to be "**P#_Practice2**" for your 2nd practice session and so forth (see picture below). If you did not understand the directions, you can re-read them before retrying the practice. When you think you have practiced enough, you can go to the next step.



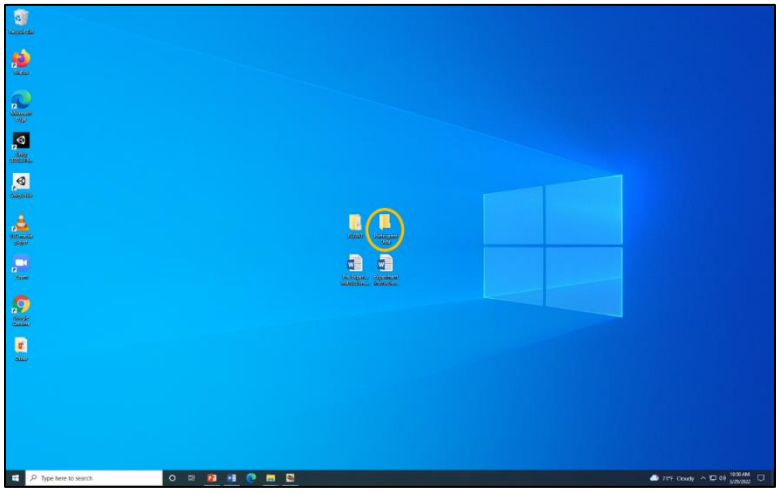
Step 3: Find and save practice data in new location
The PEBL software automatically saves your task data to a folder on the computer.

Follow this folder path to find your data:
C:\Users\Lab_Guest\Documents\pebl-exp.2.1\battery\clocktest\data

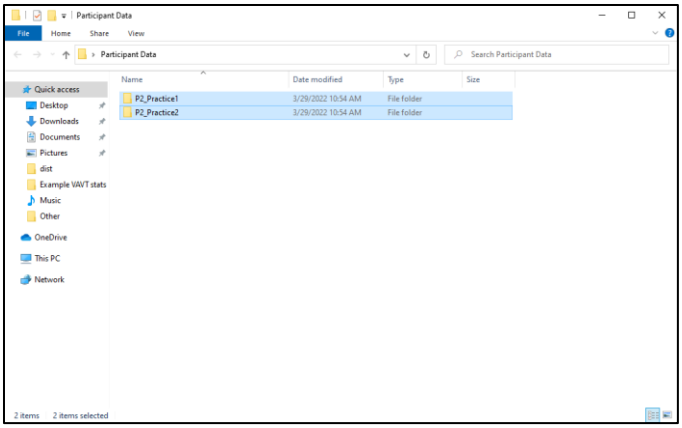
Once you get in the “data” folder, you should see one or more folders which contain your practice data. So, if you had two practice sessions, you should have two folders (as in the picture below).



Copy these folders and then open the “Participant Data” folder found on the desktop.



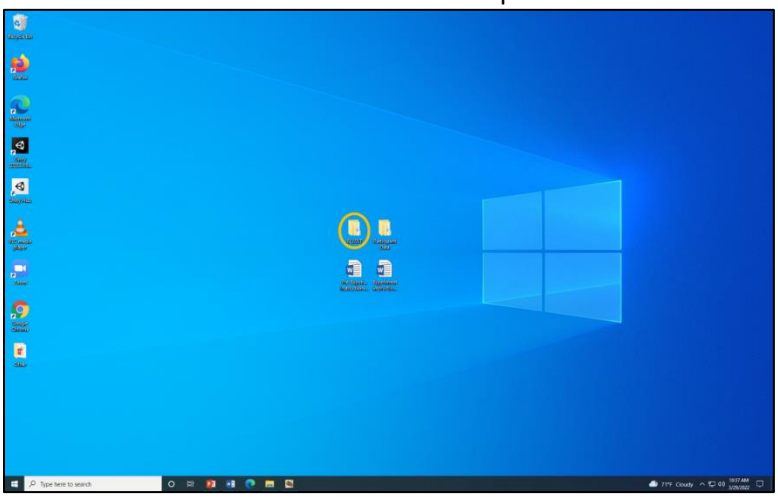
Paste the folders in this “Participant Data” folder.



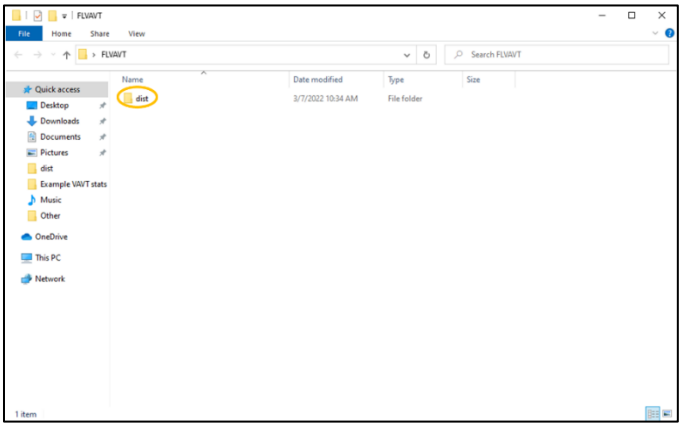
Step 4: Try out the other task and complete the practice session

The other task you may complete during the experiment is the Verbal Auditory Vigilance Task (VAVT).

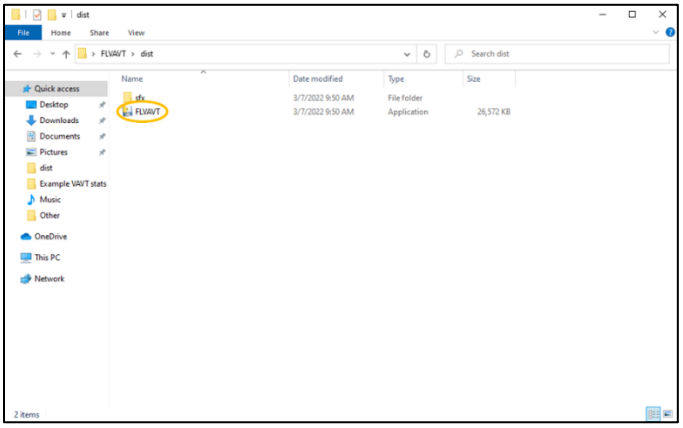
Find and open the “FLVAVT” folder located on the desktop.



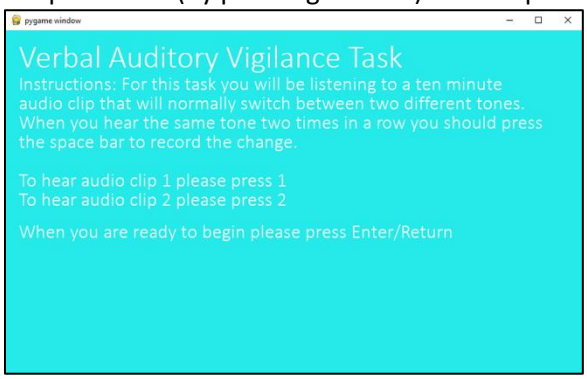
Open the “dist” subfolder.



Then open the “FLVAVT” application.



The task window should look like the image below. Please read over the instructions and then try listening to the audio clips 1 and 2 (by pressing 1 and 2). Do not press “Enter” yet.



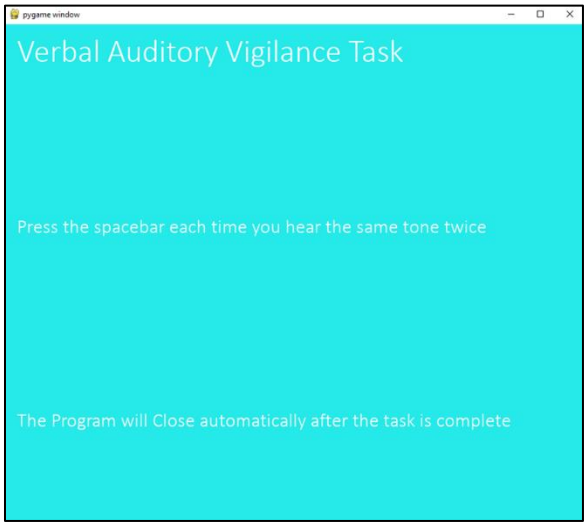
To reiterate the instructions, in this task you will be listening to a sound file composed of two different types of audio clips (tones), tone 1 and tone 2, along with periods of silence in-between. If the tones alternate (Ex: tone 1— tone 2 or tone 2— tone 1), then you should not respond. However, if the same tone repeats (Ex: tone 1— tone 1 or tone 2— tone 2), then you should respond by pressing the space bar on your keyboard as quickly as you are able.

Your performance will be graded on the following measures:

> *Detection rate*: Percentage of repetitions you detect (by pressing the space bar) [higher is better]
> *Reaction time*: The time it takes you to press the space bar when a repetition occurs [lower (quicker) is better]
> *False alarms*: The number of times you press the space bar when a repetition has not occurred [fewer is better]

For practice, you will not listen to the entire 10-minutes clip, but just about 1-minute. With the task window selected, press “Enter”. Practice performing this task until about a minute has

passed, and then close the task window using the “X” in the top right corner. **Do not perform the task for the full 10-minutes at this time.**



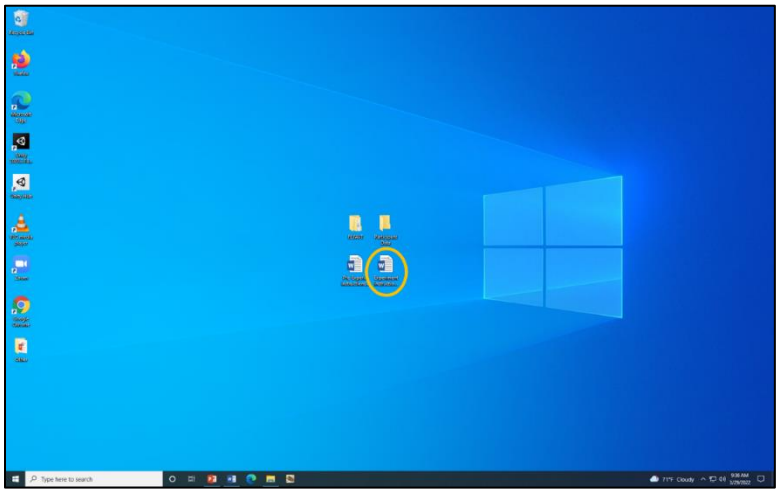
Unfortunately, you are not able to see the results from your practice session. If you do not feel that you understand how to perform the task, try re-reading the instructions and performing another ~1-minute practice session.

Summary of Steps:

Step 1: Sign the Consent Form
Step 2: Try out the PEBL software and complete the practice session
Step 3: Find and save practice data in new location
Step 4: Try out the other task and complete the practice session

---

If you have completed the above steps, then you have finished the pre-experiment. When you are ready, you can go to the next document “Experiment Instructions”.



APPENDIX E

EXPERIMENT (REMOTE) INSTRUCTIONS FOR GROUP 1

Experiment Steps (Group 1)

Thank you for agreeing to participate in this study. Before following this document, you should have already completed the steps in the document "Pre-Experiment Instructions".

***Note: Before beginning the steps in this document, you should be prepared to spend approximately 45 minutes uninterrupted. In addition, please do the following:

- Locate yourself in a quiet area and away from distractions
- Place your cell phone and any other notification devices on silent
- Inform anyone else in your residence/office/other that you need a period of uninterrupted time

It is critical to the study that you complete these steps in one sitting and without interruptions and distractions since it concerns mental fatigue and attention.

Before starting these steps, we recommend you go ahead and *read the full document* so you can more easily transition from step to step while using the document as a reference.

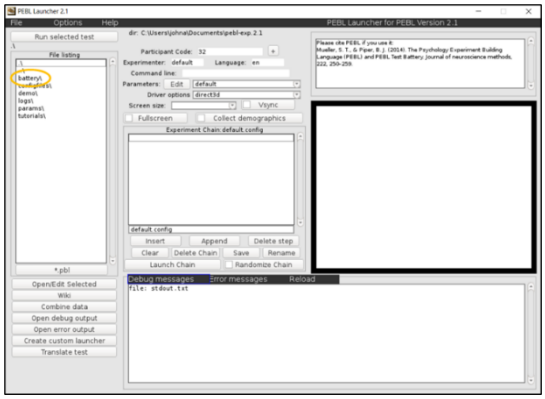
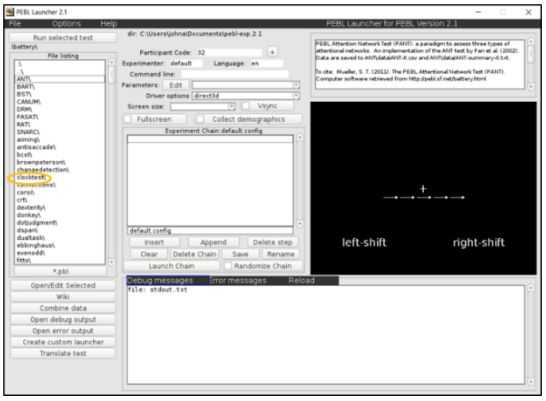
Step 1: Take the Demographic and Work Information Survey
Click on this link and complete a short survey:
https://tamu.qualtrics.com/jfe/form/SV_8l91SQDvLLendkN

Step 2: Take the Start of Experiment Subjective Ratings Survey
Click on this link and complete a second short survey:
https://tamu.qualtrics.com/jfe/form/SV_e3ack6HLEkTrIHP

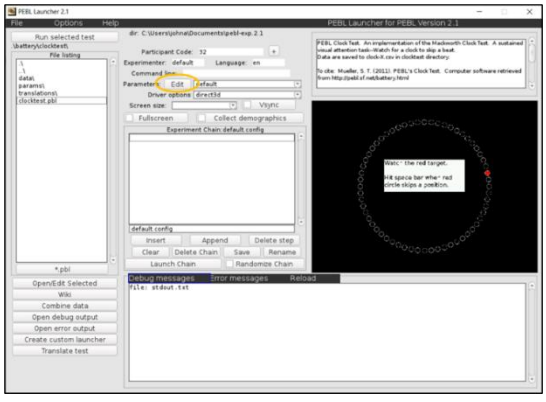
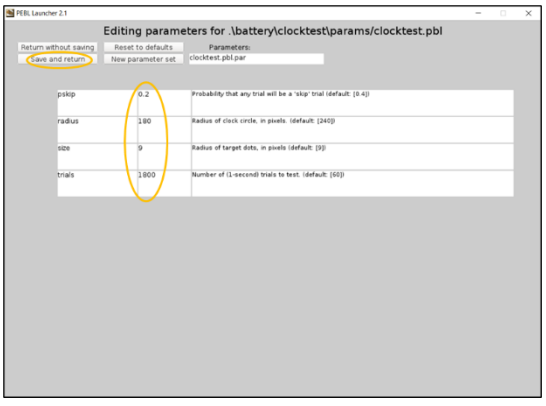
Step 3: Perform the (PEBL) clock task
This will be the full session of the clock task, which you should have previously practiced when completing the steps in the "Pre-Experiment Instructions".

Open the PEBL program which you previously installed. When it opens, it will show a window in which it asks for a password. Just click "Use without password". A pop-up will appear, and you can just click "OK".

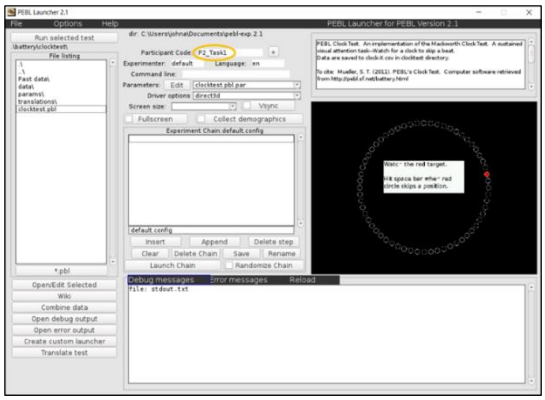
The next window is the main screen. Double-click on “battery\”. Then double-click on “clocktest\”.

In the next window, click the “Edit” button to change the parameters. In this window, change the numbers (circled in orange) to be the same as those shown in the picture below (**0.2**, **180**, **9**, and **1800**). Then click “Save and return”.

You will now be back at the previous window. In the “Participant Code” box, type in “**P#_Task1**” with your participant number in place of the “#”. For example, if you are participant 2, type in “P2_Task1”.

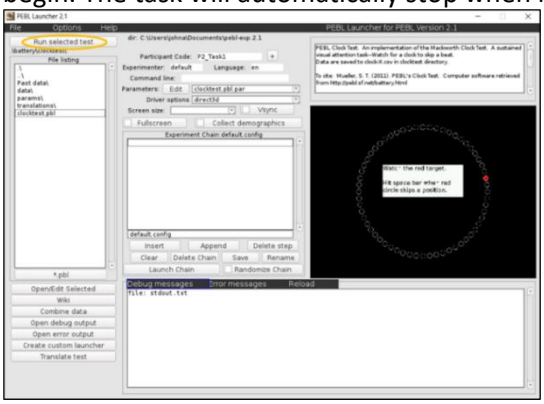


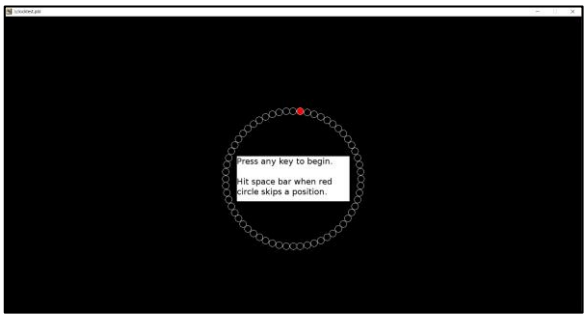
Everything is now setup for you to complete the task session. If you need a reminder of the instructions, look back at the "Pre-Experiment Instructions document".

This task session will last approximately 30 minutes, so take a moment to use the bathroom if you need to do so. In addition, you may want to adjust your computer brightness and seating arrangement to be more comfortable.

This is the most attention-critical part of the experiment, so please eliminate any distractions/potential interruptions if you have not already done so. Please try to do your best – as a reminder, up to an additional $5.00 can be earned based on your task performance.

When you are ready, you can click "Run selected test". As before, you can press any key to begin. The task will automatically stop when it finishes the set time.

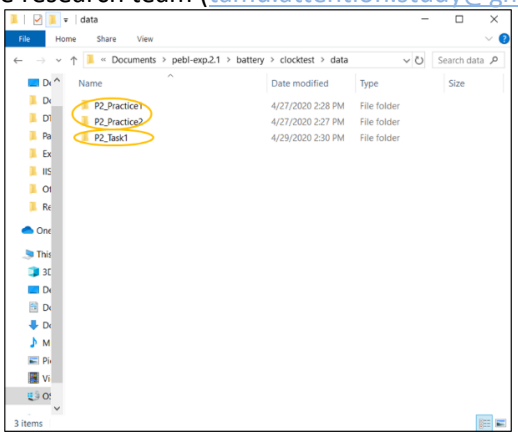




Step 4: Take the Subjective Ratings Survey
Click on this link and complete a third short survey:
https://tamu.qualtrics.com/jfe/form/SV_2mCpUgrUVgk8Mkd

Step 5: Find and email task data
Now you need to email the research team your task data. Find the "data" folder (as covered in Step 4 in the "Pre-Experiment" Instructions"). Here, you should see two or more folders which

contain your task data as well as your previous practice data. Please email the files contained in *each* of these folders to the research team (tamu.attention.study@gmail.com).



Summary of Steps:

Step 1: Take the Demographic and Work Information Survey
Step 2: Take the Start of Experiment Subjective Ratings Survey
Step 3: Perform the (PEBL) clock task
Step 4: Take the Subjective Ratings Survey
Step 5: Find and email task data

If you have completed all the above steps, then you have finished the experiment. (Note that because of your group, you did not have to perform the RAT word task.) The research team will be reviewing your performance data and then following up by email with your participation compensation.

Thank you for participating!

APPENDIX F

EXPERIMENT (REMOTE) INSTRUCTIONS FOR GROUP 2

Experiment Steps (Group 2)

Thank you for agreeing to participate in this study. Before following this document, you should have already completed the steps in the document "Pre-Experiment Instructions".

***Note: Before beginning the steps in this document, you should be prepared to spend approximately 45 minutes uninterrupted. In addition, please do the following:

- Locate yourself in a quiet area and away from distractions
- Place your cell phone and any other notification devices on silent
- Inform anyone else in your residence/office/other that you need a period of uninterrupted time
- Obtain a timer or stopwatch, which will be needed for one of the tasks

It is critical to the study that you complete these steps in one sitting and without interruptions and distractions since it concerns mental fatigue and attention.

Before starting these steps, we recommend you go ahead and *read the full document* so you can more easily transition from step to step while using the document as a reference.

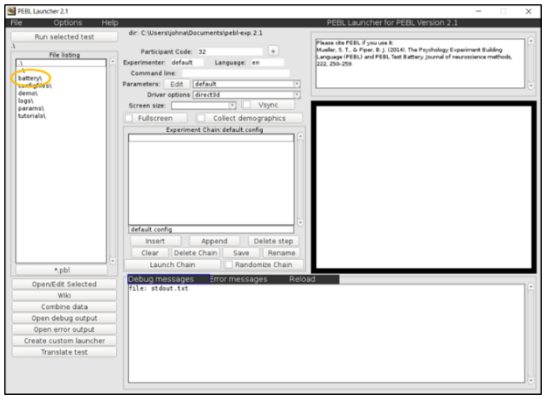
Step 1: Take the Demographic and Work Information Survey
Click on this link and complete a short survey:
https://tamu.qualtrics.com/jfe/form/SV_8l91SQDvLLendkN

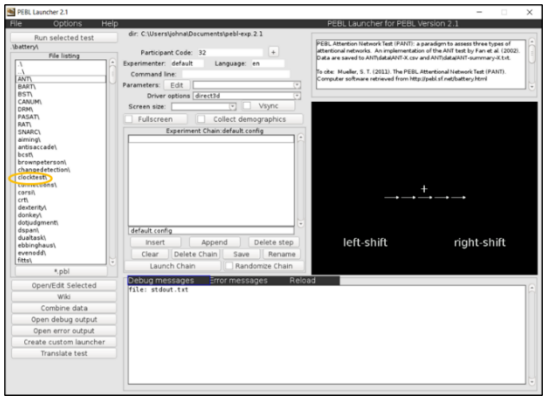
Step 2: Take the Start of Experiment Subjective Ratings Survey
Click on this link and complete a second short survey:
https://tamu.qualtrics.com/jfe/form/SV_e3ack6HLEkTrIHP

Step 3: Perform the (PEBL) clock task – Part 1 of 2
This will be the first of two full sessions of the clock task, which you should have previously practiced when completing the steps in the "Pre-Experiment Instructions".

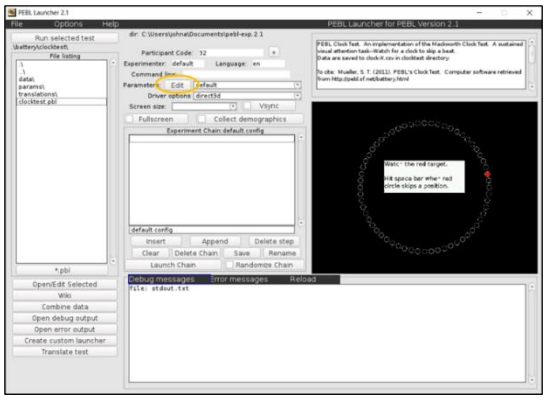
Open the PEBL program which you previously installed. When it opens, it will show a window in which it asks for a password. Just click "Use without password". A pop-up will appear, and you can just click "OK".

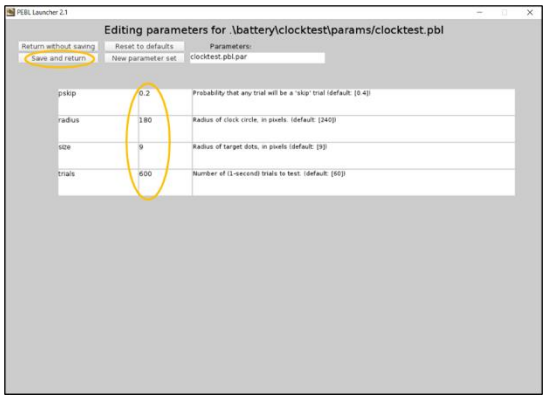
The next window is the main screen. Double-click on “battery\”. Then double-click on “clocktest\”.



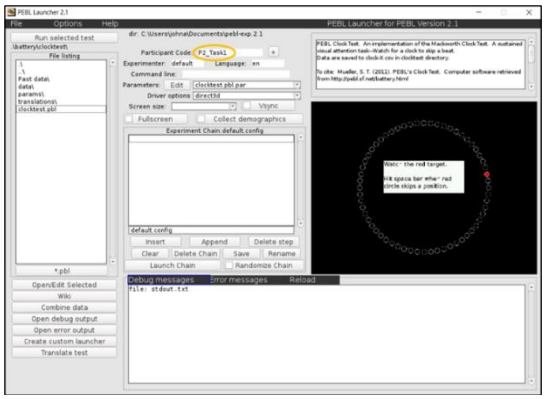


In the next window, click the “Edit” button to change the parameters. In this window, change the numbers (circled in orange) to be the same as those shown in the picture below (**0.2**, **180**, **9**, and **600**). Then click “Save and return”.



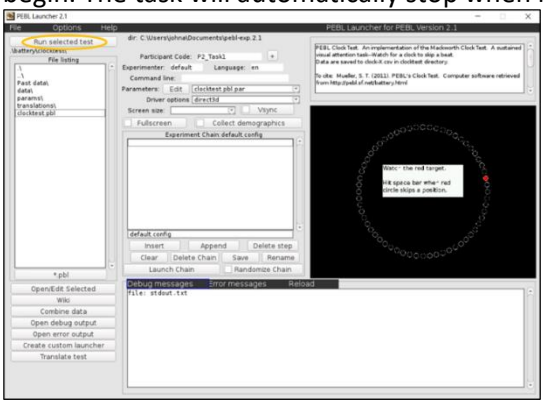


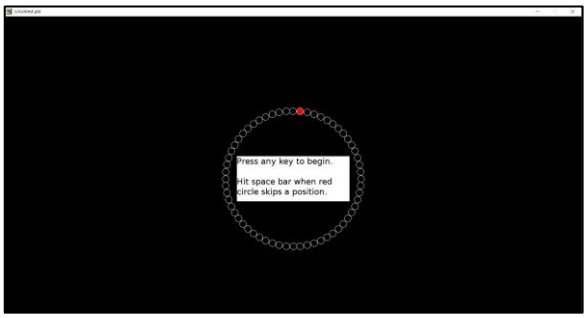
You will now be back at the previous window. In the “Participant Code” box, type in “**P#_Task1**” with your participant number in place of the “#”. For example, if you are participant 2, type in “P2_Task1”.



Everything is now setup for you to complete the task session. If you need a reminder of the instructions, look back at the “Pre-Experiment Instructions document”.

This task session will last approximately 10 minutes. It is one of the most attention-critical parts of the experiment, so please eliminate any distractions/potential interruptions if you have not already done so. In addition, you may want to adjust your computer brightness and seating arrangement to be more comfortable. Please try to do your best – as a reminder, up to an additional $5.00 can be earned based on your task performance.
When you are ready, you can click “Run selected test”. As before, you can press any key to begin. The task will automatically stop when it finishes the set time.





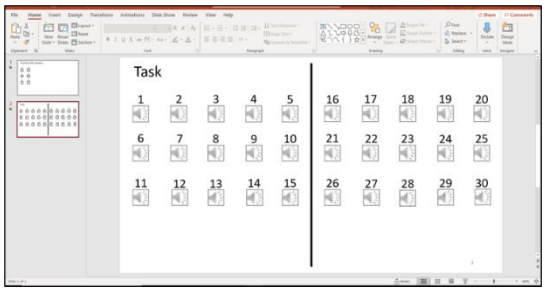
You can keep the PEBL software open since you will be coming back to it.

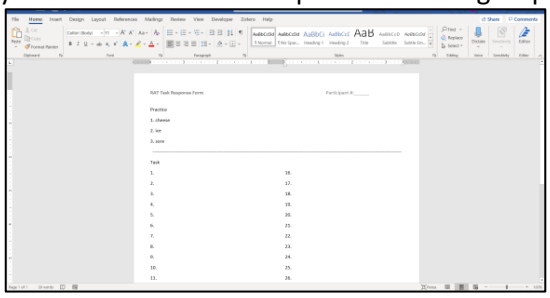
Step 4: Take the Subjective Ratings Survey
Click on this link and complete another short survey:
https://tamu.qualtrics.com/jfe/form/SV_2mCpUgrUVgk8Mkd

Step 5: Perform the RAT task
Open the PowerPoint file "RAT Task - Auditory" and go to the second slide. Also open the Word document "RAT Task Response Form". Get your timer/stopwatch and prepare it for use.

As you did in the practice session you will be listening to recordings of three words and then trying to think of a fourth word which somehow relates separately to each of the three words. (Remember you can replay the recordings if needed.) When (if) you have an answer, type it in the "RAT Task Response Form".

For this task, your performance will be based on the total number of correct answers you get (regardless of the number you attempt). So, if you cannot think of an answer for a group of words, feel free to skip it and go to the next group. If you have time later in the task and you want to try the group of words again, then you can return to them. Given the limited time you will have to complete the task, it is unlikely that you will be able to attempt all the word groups.



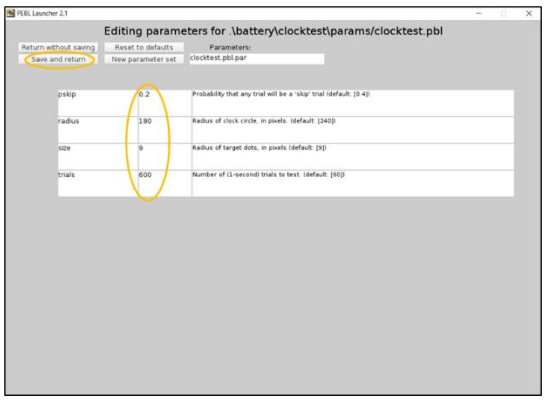


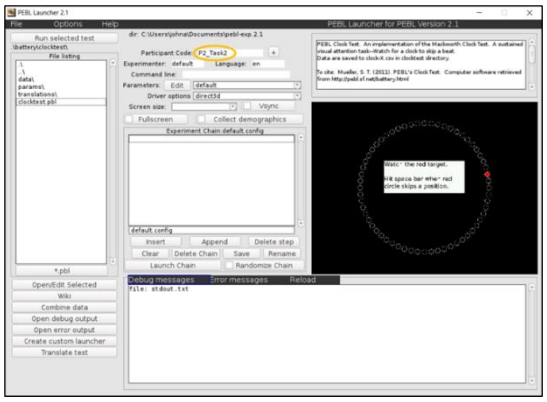
Please perform this task for ***10 minutes*** (using your timer), save the "RAT Task Response Form" file and then move on to the next step.

Step 6: Take the Subjective Ratings Survey
Click on this link and complete another short survey:
https://tamu.qualtrics.com/jfe/form/SV_2mCpUgrUVgk8Mkd

Step 7: Perform the (PEBL) clock task – Part 2 of 2
This will be the second full sessions of the clock task. Navigate to the "Edit" parameters window as you have before and make sure the parameters are the same as those shown below (**0.2**, **180**, **9**, and **600**). Then click "Save and return".

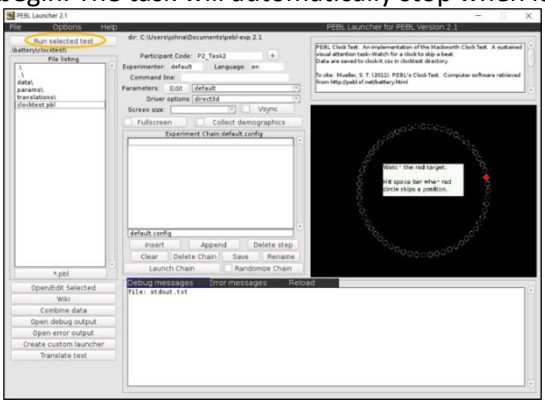
You will now be back at the previous window. In the "Participant Code" box, type in "**P#_Task2**" with your participant number in place of the "#". For example, if you are participant 2, type in "P2_Task2".

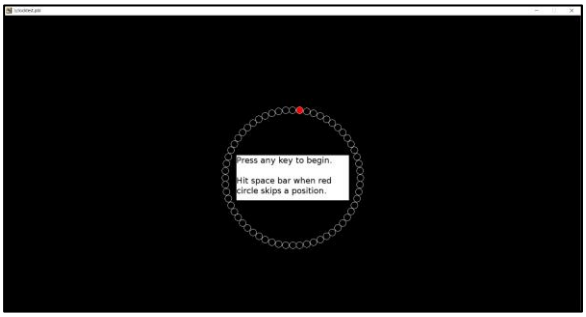




Again, this task session will last approximately 10 minutes. It is one of the most attention-critical parts of the experiment, so please eliminate any distractions/potential interruptions if you have not already done so. Please try to do your best – as a reminder, up to an additional $5.00 can be earned based on your task performance.

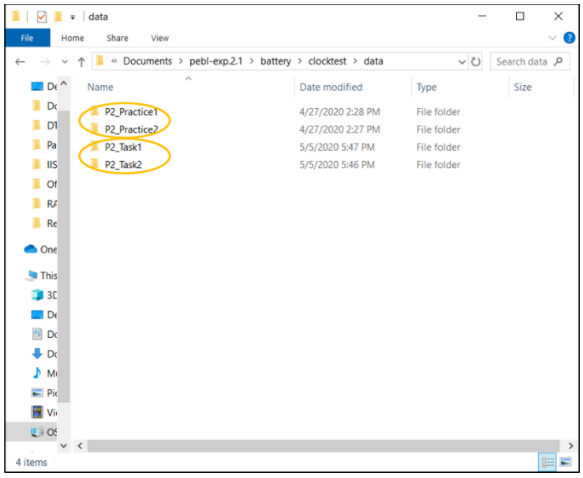
When you are ready, you can click "Run selected test". As before, you can press any key to begin. The task will automatically stop when it finishes the set time.





Step 8: Take the Subjective Ratings Survey
Click on this link and complete another short survey:
https://tamu.qualtrics.com/jfe/form/SV_2mCpUgrUVgk8Mkd

Step 9: Find and email (PEBL) clock task data
Now you need to email the research team your task data. Find the "data" folder (as covered in Step 4 in the "Pre-Experiment" Instructions"). Here, you should see three or more folders which contain your task data as well as your previous practice data. Please email the files contained in *each* of these folders to the research team (tamu.attention.study@gmail.com).



Step 10: Find and email "RAT Task Response Form"

Next you need to also email the research team your saved "RAT Task Response Form" file (it can be included in the same email as the clock task data or be sent separately).

Summary of Steps:

Step 1: Take the Demographic and Work Information Survey
Step 2: Take the Start of Experiment Subjective Ratings Survey
Step 3: Perform the (PEBL) clock task – Part 1 of 2
Step 4: Take the Subjective Ratings Survey
Step 5: Perform the RAT task
Step 6: Take the Subjective Ratings Survey
Step 7: Perform the (PEBL) clock task – Part 2 of 2
Step 8: Take the Subjective Ratings Survey
Step 9: Find and email (PEBL) clock task data
Step 10: Find and email "RAT Task Response Form"

If you have completed all the above steps, then you have finished the experiment. The research team will be reviewing your performance data and then following up by email with your participation compensation.

Thank you for participating!

APPENDIX G

EXPERIMENT (REMOTE) INSTRUCTIONS FOR GROUP 3

Experiment Steps (Group 3)

Thank you for agreeing to participate in this study. Before following this document, you should have already completed the steps in the document "Pre-Experiment Instructions".

***Note: Before beginning the steps in this document, you should be prepared to spend approximately 45 minutes uninterrupted. In addition, please do the following:

- Locate yourself in a quiet area and away from distractions
- Place your cell phone and any other notification devices on silent
- Inform anyone else in your residence/office/other that you need a period of uninterrupted time
- Obtain a timer or stopwatch, which will be needed for one of the tasks

It is critical to the study that you complete these steps in one sitting and without interruptions and distractions since it concerns mental fatigue and attention.

Before starting these steps, we recommend you go ahead and *read the full document* so you can more easily transition from step to step while using the document as a reference.

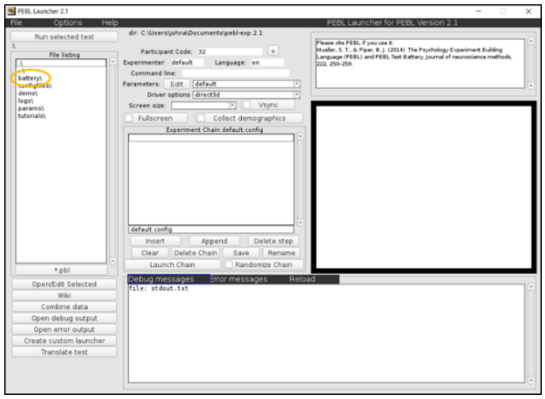
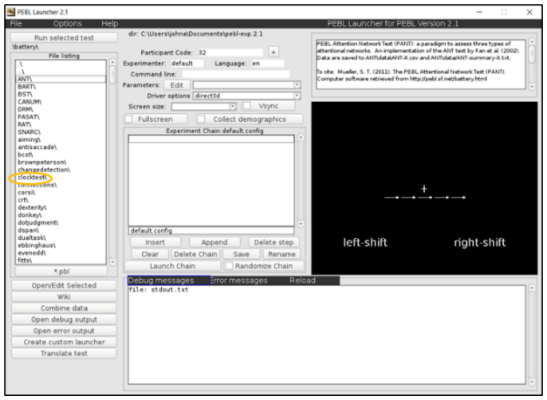
Step 1: Take the Demographic and Work Information Survey
Click on this link and complete a short survey:
https://tamu.qualtrics.com/jfe/form/SV_8l91SQDvLLendkN

Step 2: Take the Start of Experiment Subjective Ratings Survey
Click on this link and complete a second short survey:
https://tamu.qualtrics.com/jfe/form/SV_e3ack6HLEkTrIHP

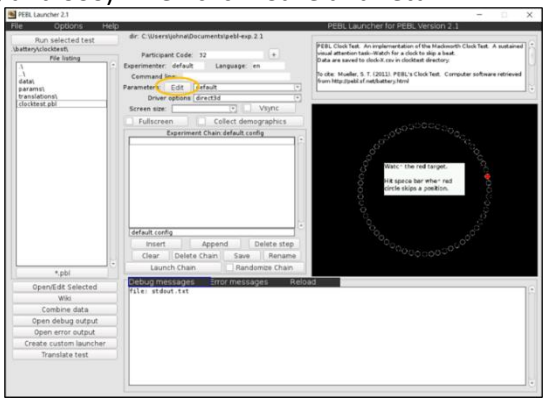
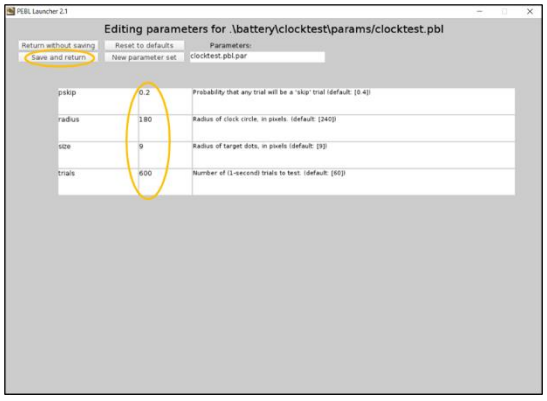
Step 3: Perform the (PEBL) clock task – Part 1 of 2
This will be the first of two full sessions of the clock task, which you should have previously practiced when completing the steps in the "Pre-Experiment Instructions".

Open the PEBL program which you previously installed. When it opens, it will show a window in which it asks for a password. Just click "Use without password". A pop-up will appear, and you can just click "OK".

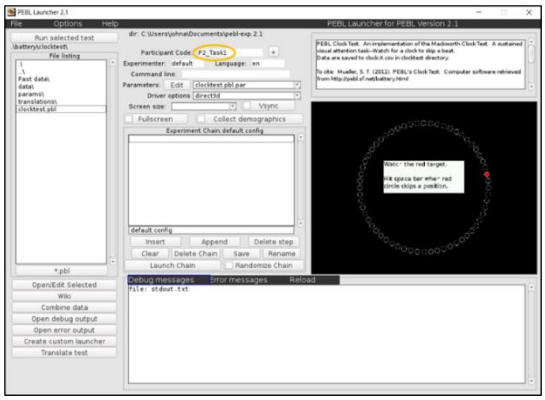
The next window is the main screen. Double-click on “battery\”. Then double-click on “clocktest\”.

In the next window, click the “Edit” button to change the parameters. In this window, change the numbers (circled in orange) to be the same as those shown in the picture below (**0.2**, **180**, **9**, and **600**). Then click “Save and return”.

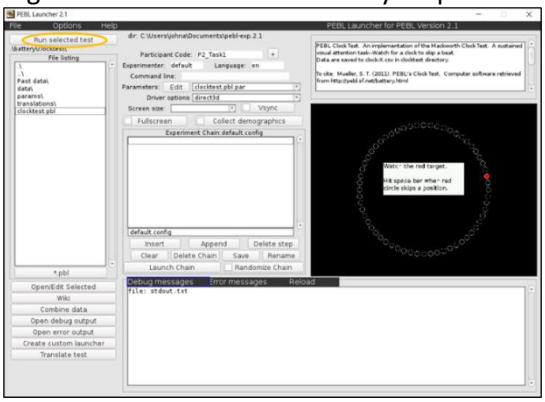



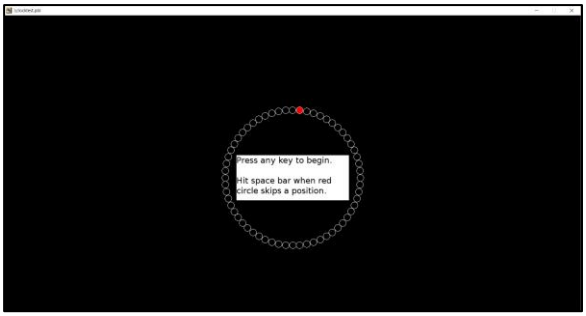
You will now be back at the previous window. In the “Participant Code” box, type in “**P#_Task1**” with your participant number in place of the “#”. For example, if you are participant 2, type in “P2_Task1”.



Everything is now setup for you to complete the task session. If you need a reminder of the instructions, look back at the "Pre-Experiment Instructions document".

This task session will last approximately 10 minutes. It is one of the most attention-critical parts of the experiment, so please eliminate any distractions/potential interruptions if you have not already done so. In addition, you may want to adjust your computer brightness and seating arrangement to be more comfortable. Please try to do your best – as a reminder, up to an additional $5.00 can be earned based on your task performance.
When you are ready, you can click "Run selected test". As before, you can press any key to begin. The task will automatically stop when it finishes the set time.





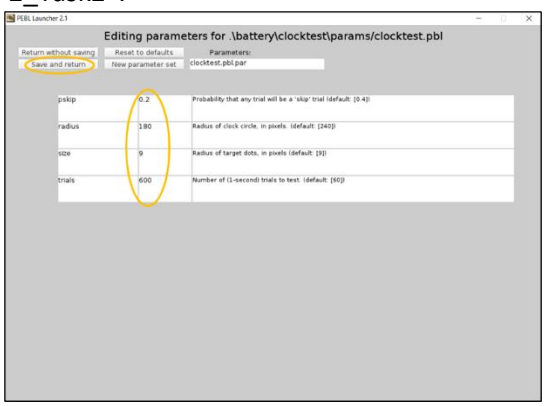
You can keep the PEBL software open since you will be coming back to it.

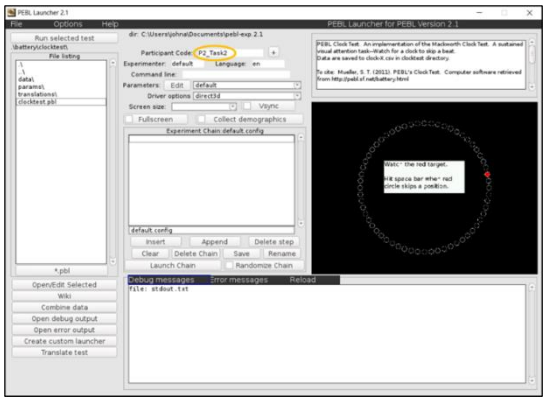
Step 4: Take the Subjective Ratings Survey
Click on this link and complete another short survey:
https://tamu.qualtrics.com/jfe/form/SV_2mCpUgrUVgk8Mkd

Step 5: Take a rest break
While remaining at your computer, set your timer for 10 minutes. Please rest for *10 minutes* by doing nothing. If you would like to, you may close your eyes during this time. After the time is complete, move on to the next step.

Step 6: Perform the (PEBL) clock task – Part 2 of 2
This will be the second full sessions of the clock task. Navigate to the "Edit" parameters window as you have before and make sure the parameters are the same as those shown below (**0.2**, **180**, **9**, and **600**). Then click "Save and return".

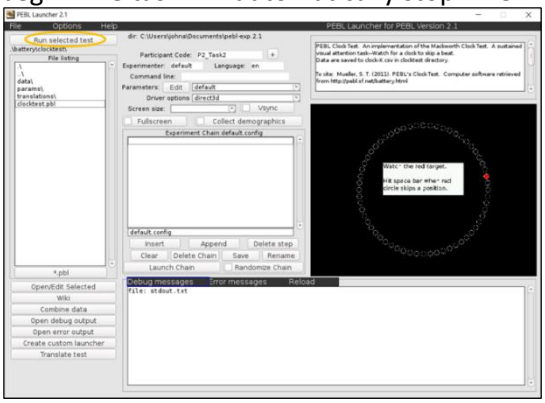
You will now be back at the previous window. In the "Participant Code" box, type in "**P#_Task2**" with your participant number in place of the "#". For example, if you are participant 2, type in "P2_Task2".

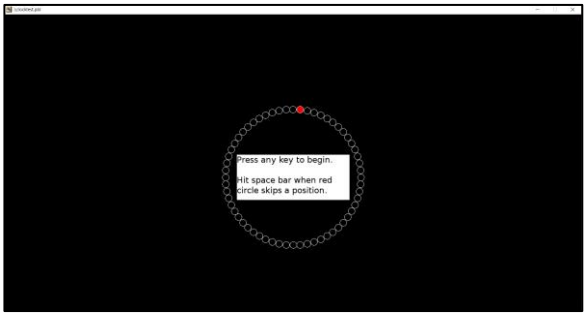




Again, this task session will last approximately 10 minutes. It is one of the most attention-critical parts of the experiment, so please eliminate any distractions/potential interruptions if you have not already done so. Please try to do your best – as a reminder, up to an additional $5.00 can be earned based on your task performance.

When you are ready, you can click "Run selected test". As before, you can press any key to begin. The task will automatically stop when it finishes the set time.

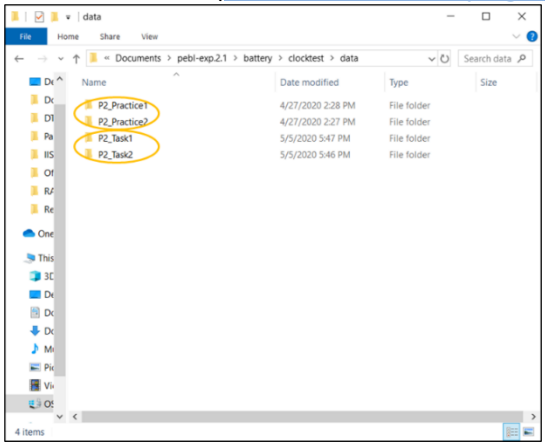




Step 7: Take the Subjective Ratings Survey
Click on this link and complete another short survey:
https://tamu.qualtrics.com/jfe/form/SV_2mCpUgrUVgk8Mkd

Step 8: Find and email task data

Now you need to email the research team your task data. Find the "data" folder (as covered in Step 4 in the "Pre-Experiment" Instructions"). Here, you should see three or more folders which contain your task data as well as your previous practice data. Please email the files contained in *each* of these folders to the research team (tamu.attention.study@gmail.com).



Summary of Steps:

Step 1: Take the Demographic and Work Information Survey
Step 2: Take the Start of Experiment Subjective Ratings Survey
Step 3: Perform the (PEBL) clock task – Part 1 of 2
Step 4: Take the Subjective Ratings Survey
Step 5: Take a rest break
Step 6: Perform the (PEBL) clock task – Part 2 of 2
Step 7: Take the Subjective Ratings Survey
Step 8: Find and email task data

If you have completed all the above steps, then you have finished the experiment. (Note that because of your group, you did not have to perform the RAT word task.) The research team will be reviewing your performance data and then following up by email with your participation compensation.

Thank you for participating!

APPENDIX H

EXPERIMENT (REMOTE) INSTRUCTIONS FOR GROUP 4

Experiment Steps (Group 4)

Thank you for agreeing to participate in this study. Before following this document, you should have already completed the steps in the document "Pre-Experiment Instructions (for Group 4)".

***Note: Before beginning the steps in this document, you should be prepared to spend approximately 45 minutes uninterrupted. In addition, please do the following:

- Locate yourself in a quiet area and away from distractions
- Place your cell phone and any other notification devices on silent
- Inform anyone else in your residence/office/other that you need a period of uninterrupted time
- Obtain a timer or stopwatch, which will be needed for one of the tasks

It is critical to the study that you complete these steps in one sitting and without interruptions and distractions since it concerns mental fatigue and attention.

Before starting these steps, we recommend you go ahead and *read the full document* so you can more easily transition from step to step while using the document as a reference.

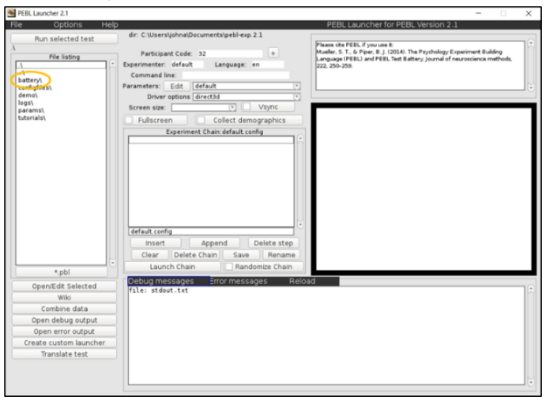
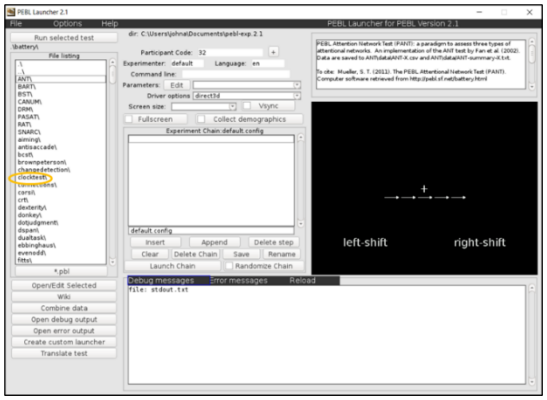
Step 1: Take the Demographic and Work Information Survey
Click on this link and complete a short survey:
https://tamu.qualtrics.com/jfe/form/SV_8l91SQDvLLendkN

Step 2: Take the Start of Experiment Subjective Ratings Survey
Click on this link and complete a second short survey:
https://tamu.qualtrics.com/jfe/form/SV_e3ack6HLEkTrIHP

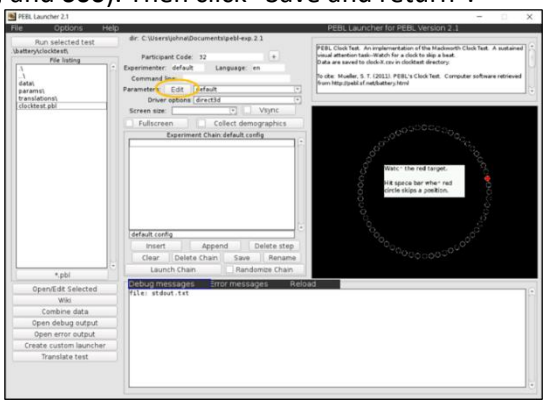
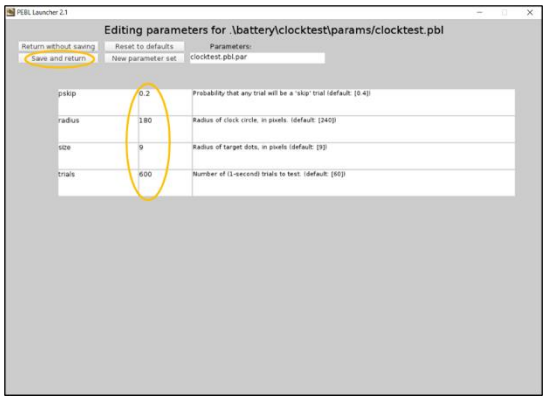
Step 3: Perform the (PEBL) clock task – Part 1 of 2
This will be the first of two full sessions of the clock task, which you should have previously practiced when completing the steps in the "Pre-Experiment Instructions".

Open the PEBL program which you previously installed. When it opens, it will show a window in which it asks for a password. Just click "Use without password". A pop-up will appear, and you can just click "OK".

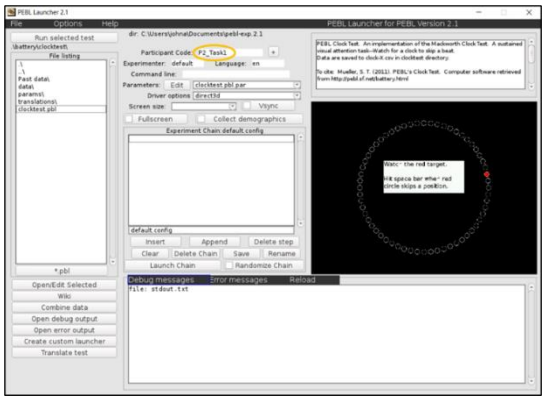
The next window is the main screen. Double-click on “battery\”. Then double-click on “clocktest\”.

In the next window, click the “Edit” button to change the parameters. In this window, change the numbers (circled in orange) to be the same as those shown in the picture below (**0.2**, **180**, **9**, and **600**). Then click “Save and return”.

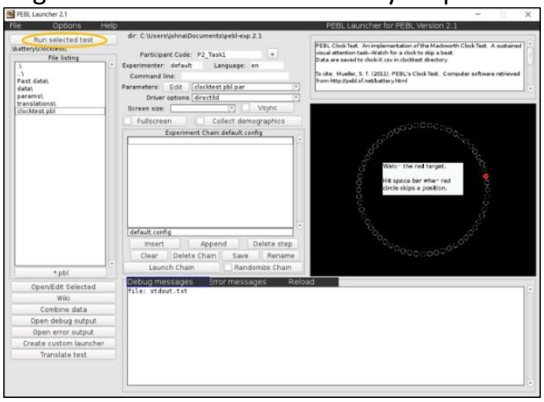



You will now be back at the previous window. In the “Participant Code” box, type in “**P#_Task1**” with your participant number in place of the “#”. For example, if you are participant 2, type in “P2_Task1”.



Everything is now setup for you to complete the task session. If you need a reminder of the instructions, look back at the "Pre-Experiment Instructions" document.

This task session will last approximately 10 minutes. It is one of the most attention-critical parts of the experiment, so please eliminate any distractions/potential interruptions if you have not already done so. In addition, you may want to adjust your computer brightness and seating arrangement to be more comfortable. Please try to do your best – as a reminder, up to an additional $5.00 can be earned based on your task performance.
When you are ready, you can click "Run selected test". As before, you can press any key to begin. The task will automatically stop when it finishes the set time.



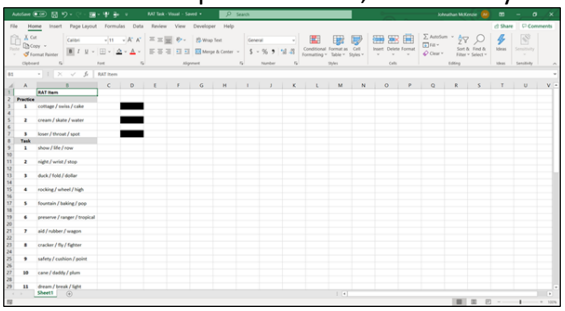
You can keep the PEBL software open since you will be coming back to it.

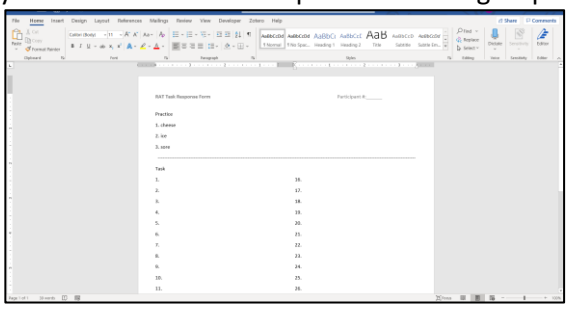
Step 4: Take the Subjective Ratings Survey
Click on this link and complete another short survey:
https://tamu.qualtrics.com/jfe/form/SV_2mCpUgrUVgk8Mkd

Step 5: Perform the RAT task
Open the Excel file "RAT Task - Visual". Also open the Word document "RAT Task Response Form". Get your timer/stopwatch and prepare it for use.

As you did in the practice session you will be reading groups of three words and then trying to think of a fourth word which somehow relates separately to each of the three words. When (if) you have an answer, type it in the "RAT Task Response Form".

For this task, your performance will be based on the total number of correct answers you get (regardless of the number you attempt). So, if you cannot think of an answer for a group of words, feel free to skip it and go to the next group. If you have time later in the task and you want to try the group of words again, then you can return to them. Given the limited time you will have to complete the task, it is unlikely that you will be able to attempt all the word groups.



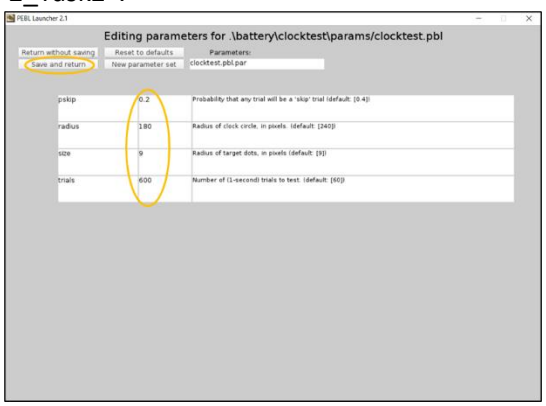


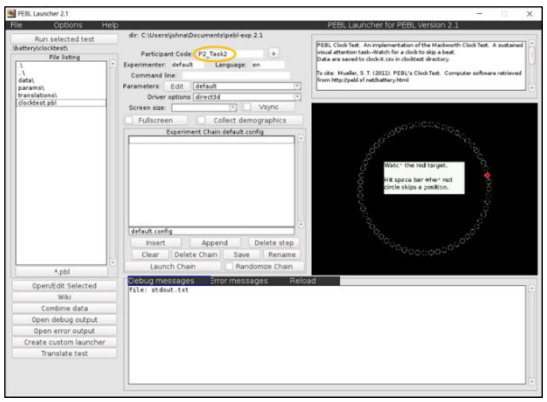
Please perform this task for ***10 minutes*** (using your timer), save the "RAT Task Response Form" file and then move on to the next step.

Step 6: Take the Subjective Ratings Survey
Click on this link and complete another short survey:
https://tamu.qualtrics.com/jfe/form/SV_2mCpUgrUVgk8Mkd

Step 7: Perform the (PEBL) clock task – Part 2 of 2
This will be the second full sessions of the clock task. Navigate to the "Edit" parameters window as you have before and make sure the parameters are the same as those shown below (**0.2**, **180**, **9**, and **600**). Then click "Save and return".

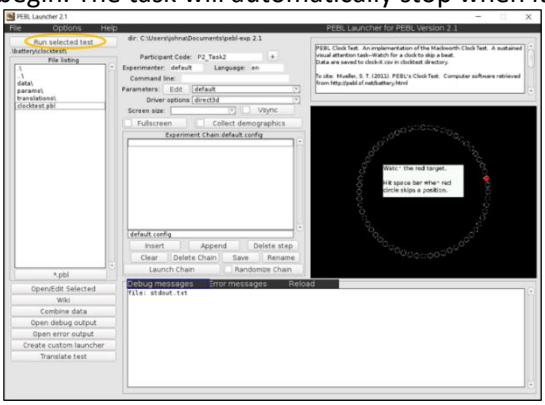
You will now be back at the previous window. In the "Participant Code" box, type in "**P#_Task2**" with your participant number in place of the "#". For example, if you are participant 2, type in "P2_Task2".

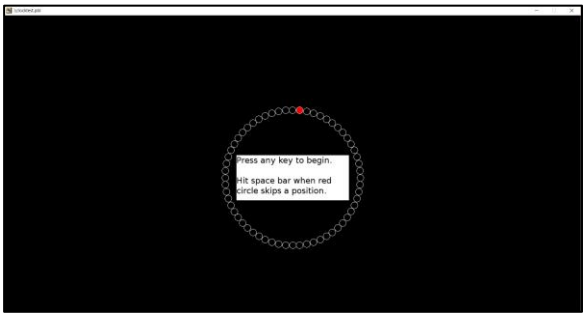




Again, this task session will last approximately 10 minutes. It is one of the most attention-critical parts of the experiment, so please eliminate any distractions/potential interruptions if you have not already done so. Please try to do your best – as a reminder, up to an additional $5.00 can be earned based on your task performance.

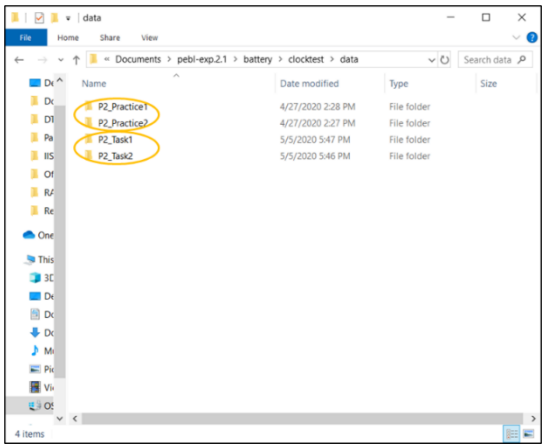
When you are ready, you can click "Run selected test". As before, you can press any key to begin. The task will automatically stop when it finishes the set time.





Step 8: Take the Subjective Ratings Survey
Click on this link and complete another short survey:
https://tamu.qualtrics.com/jfe/form/SV_2mCpUgrUVgk8Mkd

Step 9: Find and email (PEBL) clock task data
Now you need to email the research team your task data. Find the "data" folder (as covered in Step 4 in the "Pre-Experiment" Instructions"). Here, you should see three or more folders which contain your task data as well as your previous practice data. Please email the files contained in *each* of these folders to the research team (tamu.attention.study@gmail.com).



Step 10: Find and email "RAT Task Response Form"
Next you need to also email the research team your saved "RAT Task Response Form" file (it can be included in the same email as the clock task data or be sent separately).

Summary of Steps:

Step 1: Take the Demographic and Work Information Survey
Step 2: Take the Start of Experiment Subjective Ratings Survey
Step 3: Perform the (PEBL) clock task – Part 1 of 2
Step 4: Take the Subjective Ratings Survey
Step 5: Perform the RAT task
Step 6: Take the Subjective Ratings Survey
Step 7: Perform the (PEBL) clock task – Part 2 of 2
Step 8: Take the Subjective Ratings Survey
Step 9: Find and email (PEBL) clock task data
Step 10: Find and email "RAT Task Response Form"

If you have completed all the above steps, then you have finished the experiment. The research team will be reviewing your performance data and then following up by email with your participation compensation.

Thank you for participating!

APPENDIX I

EXPERIMENT (REMOTE) INSTRUCTIONS FOR GROUP 5

Experiment Steps (Group 5)

Thank you for agreeing to participate in this study. Before following this document, you should have already completed the steps in the document "Pre-Experiment Instructions (for Group 5)".

***Note: Before beginning the steps in this document, you should be prepared to spend approximately 45 minutes uninterrupted. In addition, please do the following:

- Locate yourself in a quiet area and away from distractions
- Place your cell phone and any other notification devices on silent
- Inform anyone else in your residence/office/other that you need a period of uninterrupted time
- Obtain a timer or stopwatch, which will be needed for one of the tasks

It is critical to the study that you complete these steps in one sitting and without interruptions and distractions since it concerns mental fatigue and attention.

Before starting these steps, we recommend you go ahead and *read the full document* so you can more easily transition from step to step while using the document as a reference.

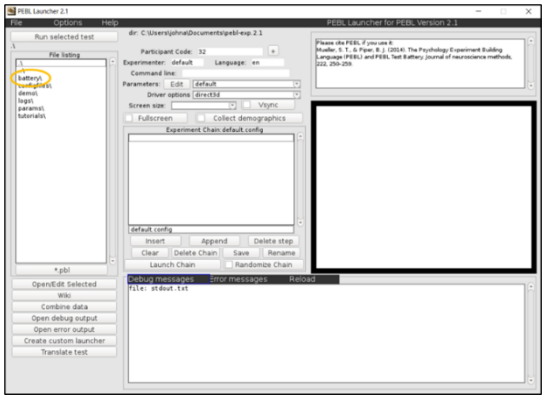
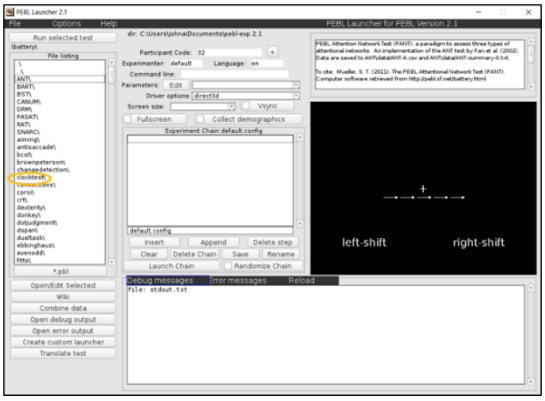
Step 1: Take the Demographic and Work Information Survey
Click on this link and complete a short survey:
https://tamu.qualtrics.com/jfe/form/SV_8l91SQDvLLendkN

Step 2: Take the Start of Experiment Subjective Ratings Survey
Click on this link and complete a second short survey:
https://tamu.qualtrics.com/jfe/form/SV_e3ack6HLEkTrIHP

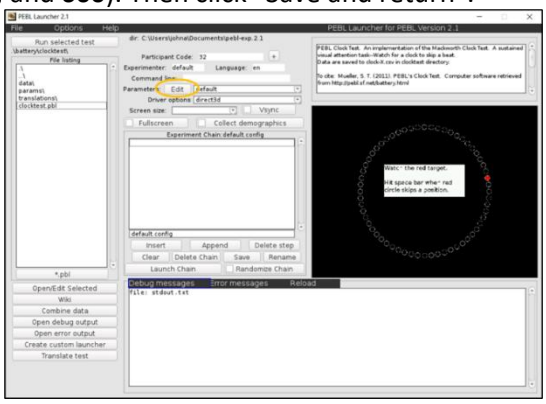
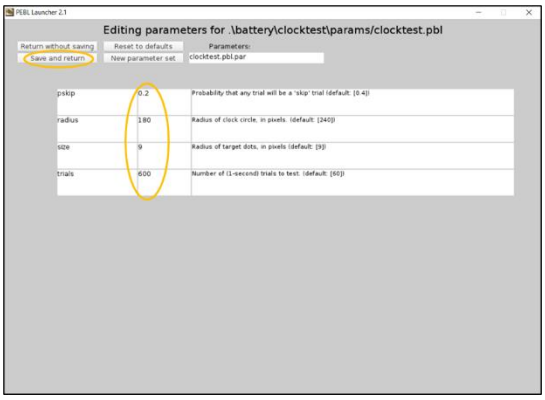
Step 3: Perform the (PEBL) clock task – Part 1 of 2
This will be the first of two full sessions of the clock task, which you should have previously practiced when completing the steps in the "Pre-Experiment Instructions".

Open the PEBL program which you previously installed. When it opens, it will show a window in which it asks for a password. Just click "Use without password". A pop-up will appear, and you can just click "OK".

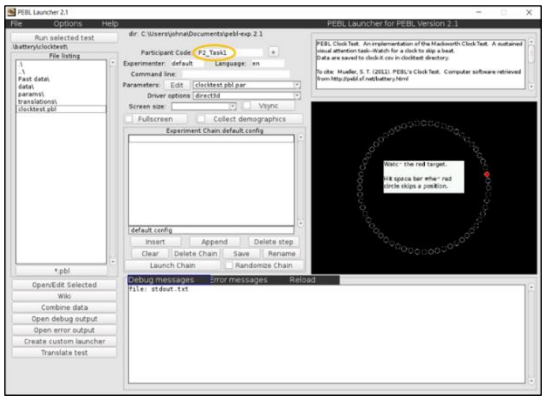
The next window is the main screen. Double-click on “battery\”. Then double-click on “clocktest\”.

In the next window, click the “Edit” button to change the parameters. In this window, change the numbers (circled in orange) to be the same as those shown in the picture below (**0.2**, **180**, **9**, and **600**). Then click “Save and return”.

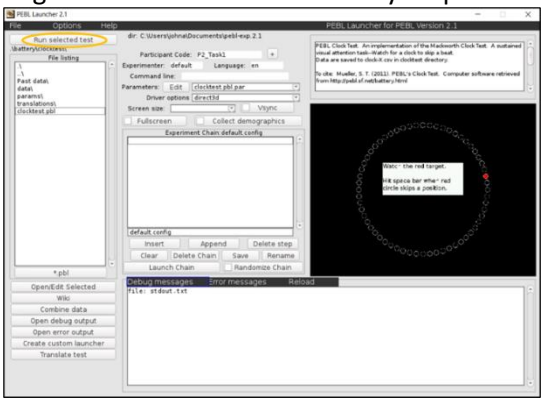



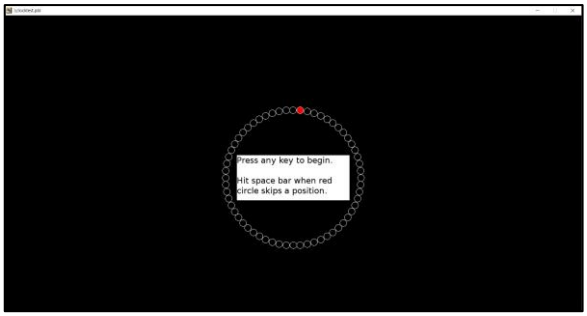
You will now be back at the previous window. In the “Participant Code” box, type in “**P#_Task1**” with your participant number in place of the “#”. For example, if you are participant 2, type in “P2_Task1”.



Everything is now setup for you to complete the task session. If you need a reminder of the instructions, look back at the "Pre-Experiment Instructions document".

This task session will last approximately 10 minutes. It is one of the most attention-critical parts of the experiment, so please eliminate any distractions/potential interruptions if you have not already done so. In addition, you may want to adjust your computer brightness and seating arrangement to be more comfortable. Please try to do your best – as a reminder, up to an additional $5.00 can be earned based on your task performance.
When you are ready, you can click "Run selected test". As before, you can press any key to begin. The task will automatically stop when it finishes the set time.





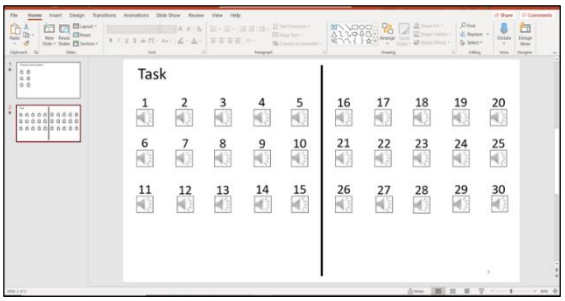
You can keep the PEBL software open since you will be coming back to it.

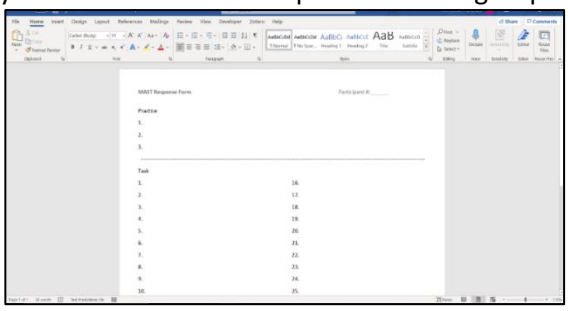
Step 4: Take the Subjective Ratings Survey
Click on this link and complete another short survey:
https://tamu.qualtrics.com/jfe/form/SV_2mCpUgrUVgk8Mkd

Step 5: Perform the MAST
Open the PowerPoint file "MAST - Auditory" and go to the second slide. Also open the Word document "MAST Response Form". Get your timer/stopwatch and prepare it for use.

As you did in the practice session you will be listening to recordings of three state names and then trying to think of a fourth state that is adjacent to (shares a border with) each of the three given states. (Remember you can replay the recordings if needed.) When (if) you have an answer, type it in the "MAST Response Form".

For this task, your performance will be based on the total number of correct answers you get (regardless of the number you attempt). So, if you cannot think of an answer for a group of states, feel free to skip it and go to the next group. If you have time later in the task and you want to try the group of states again, then you can return to them. Given the limited time you will have to complete the task, it is unlikely that you will be able to attempt all the state groups.



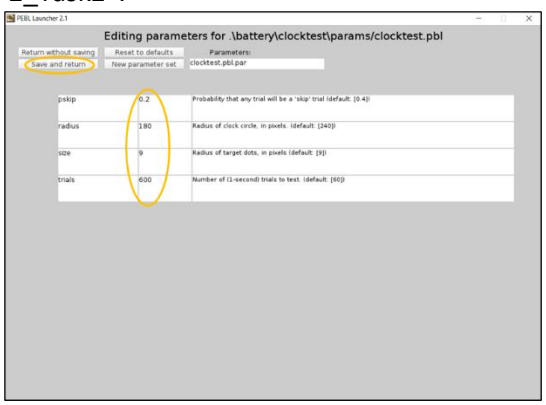


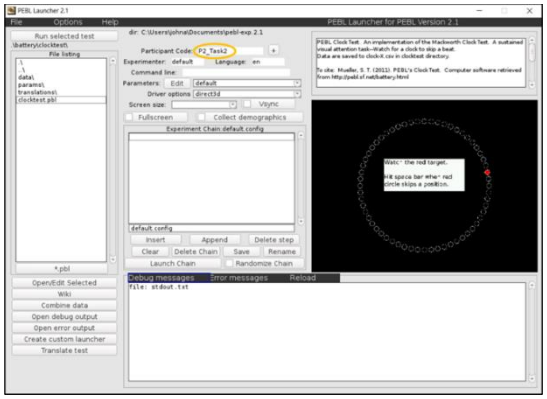
Please perform this task for ***10 minutes*** (using your timer), save the "MAST Response Form" file and then move on to the next step.

Step 6: Take the Subjective Ratings Survey
Click on this link and complete another short survey:
https://tamu.qualtrics.com/jfe/form/SV_2mCpUgrUVgk8Mkd

Step 7: Perform the (PEBL) clock task – Part 2 of 2
This will be the second full sessions of the clock task. Navigate to the "Edit" parameters window as you have before and make sure the parameters are the same as those shown below (**0.2**, **180**, **9**, and **600**). Then click "Save and return".

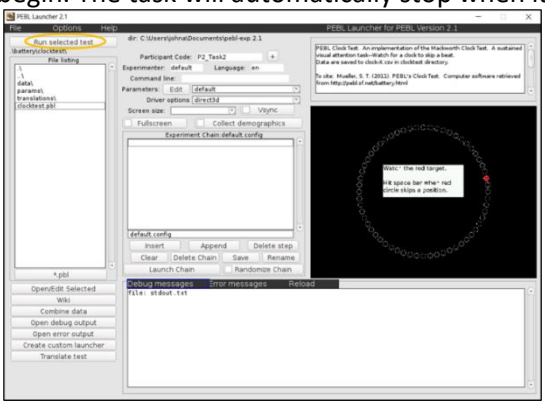
You will now be back at the previous window. In the "Participant Code" box, type in "**P#_Task2**" with your participant number in place of the "#". For example, if you are participant 2, type in "P2_Task2".

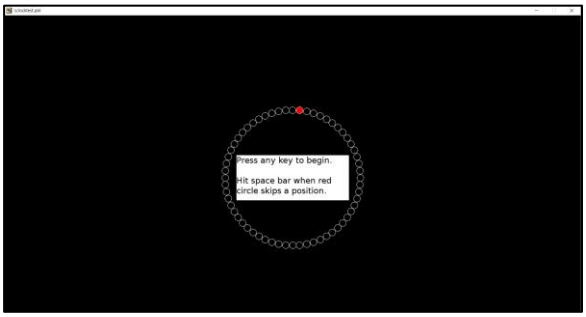




Again, this task session will last approximately 10 minutes. It is one of the most attention-critical parts of the experiment, so please eliminate any distractions/potential interruptions if you have not already done so. Please try to do your best – as a reminder, up to an additional $5.00 can be earned based on your task performance.

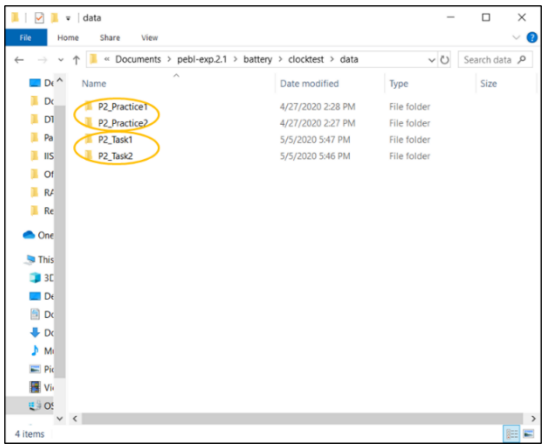
When you are ready, you can click "Run selected test". As before, you can press any key to begin. The task will automatically stop when it finishes the set time.





Step 8: Take the Subjective Ratings Survey
Click on this link and complete another short survey:
https://tamu.qualtrics.com/jfe/form/SV_2mCpUgrUVgk8Mkd

Step 9: Find and email (PEBL) clock task data
Now you need to email the research team your task data. Find the "data" folder (as covered in Step 4 in the "Pre-Experiment" Instructions"). Here, you should see three or more folders which contain your task data as well as your previous practice data. Please email the files contained in *each* of these folders to the research team (tamu.attention.study@gmail.com).



Step 10: Find and email "MAST Response Form"
Next you need to also email the research team your saved "MAST Response Form" file (it can be included in the same email as the clock task data or be sent separately).

Summary of Steps:

Step 1: Take the Demographic and Work Information Survey
Step 2: Take the Start of Experiment Subjective Ratings Survey
Step 3: Perform the (PEBL) clock task – Part 1 of 2
Step 4: Take the Subjective Ratings Survey
Step 5: Perform the MAST
Step 6: Take the Subjective Ratings Survey
Step 7: Perform the (PEBL) clock task – Part 2 of 2
Step 8: Take the Subjective Ratings Survey
Step 9: Find and email (PEBL) clock task data
Step 10: Find and email "MAST Response Form"

If you have completed all the above steps, then you have finished the experiment. The research team will be reviewing your performance data and then following up by email with your participation compensation.

Thank you for participating!

APPENDIX J

EXPERIMENT INSTRUCTIONS FOR GROUP 6

Experiment Steps (Group 6)

Thank you for agreeing to participate in this study. Before following this document, you should have already completed the steps in the document "Pre-Experiment Instructions (for Group 6)".

***Note: Before beginning the steps in this document, you should be prepared to spend approximately 45 minutes uninterrupted. In addition, please do the following:

- Place your cell phone and any other notification devices on silent
- Take a bathroom break if needed

It is critical to the study that you complete these steps in one sitting and without interruptions and distractions since it concerns mental fatigue and attention.

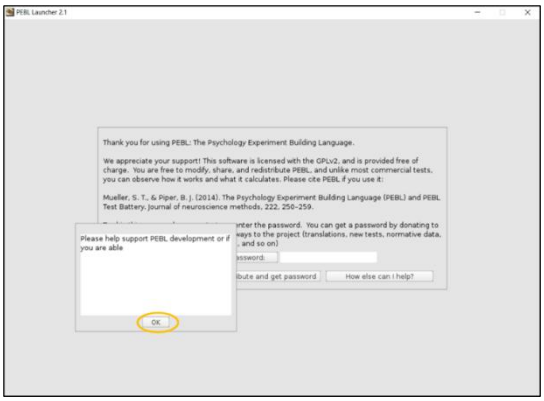
Before starting these steps, we recommend you go ahead and *read the full document* so you can more easily transition from step to step while using the document as a reference.

Step 1: Take the Demographic and Work Information Survey
Click on this link and complete a short survey:
https://tamu.qualtrics.com/jfe/form/SV_8l91SQDvLLendkN

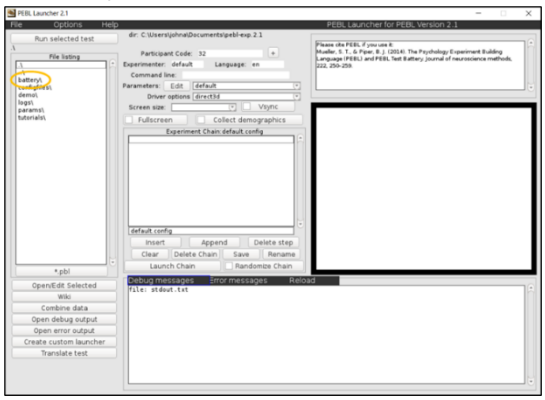
Step 2: Take the Start of Experiment Subjective Ratings Survey
Click on this link and complete a second short survey:
https://tamu.qualtrics.com/jfe/form/SV_e3ack6HLEkTrIHP

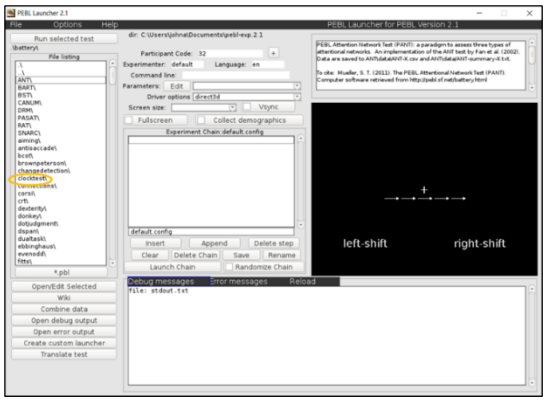
Step 3: Perform the (PEBL) clock task – Part 1 of 2
This will be the first of two full sessions of the clock task, which you should have previously practiced when completing the steps in the "Pre-Experiment Instructions".

Open the PEBL program. When it opens, it will show a window in which it asks for a password. Just click "Use without password". A pop-up will appear, and you can just click "OK".

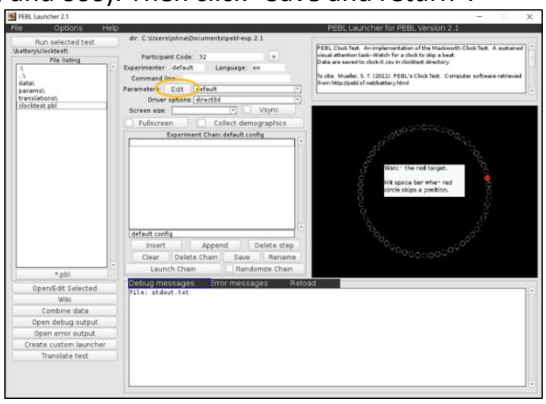


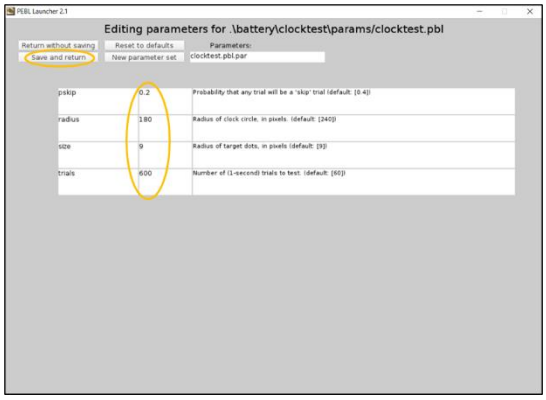
The next window is the main screen. Double-click on “battery\”. Then double-click on “clocktest\”.



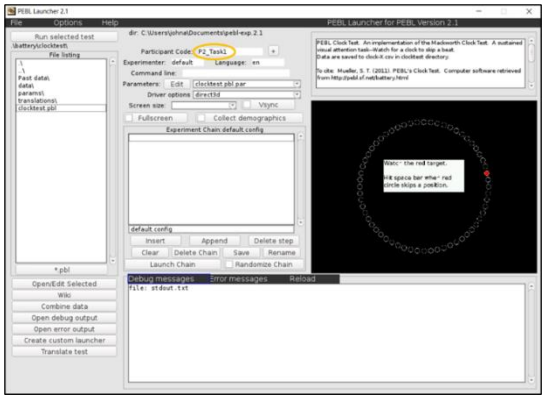


In the next window, click the “Edit” button to change the parameters. In this window, change the numbers (circled in orange) to be the same as those shown in the picture below (**0.2**, **180**, **9**, and **600**). Then click “Save and return”.



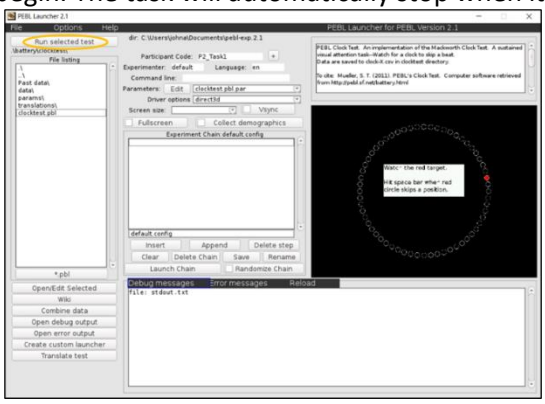


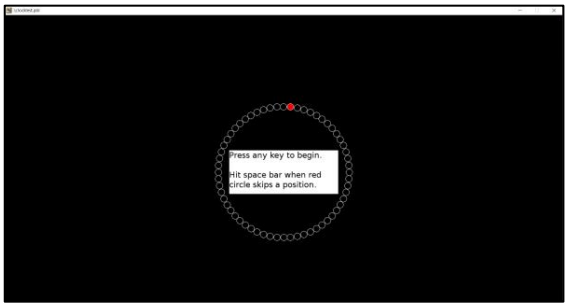
You will now be back at the previous window. In the “Participant Code” box, type in “**P#_Task1**” with your participant number in place of the “#”. For example, if you are participant 2, type in “P2_Task1”.



Everything is now setup for you to complete the task session. If you need a reminder of the instructions, look back at the “Pre-Experiment Instructions document”.

This task session will last approximately 10 minutes. It is one of the most attention-critical parts of the experiment, so please eliminate any distractions/potential interruptions if you have not already done so. In addition, you may want to adjust your seating arrangement to be more comfortable. Please try to do your best – as a reminder, up to an additional $5.00 can be earned based on your task performance.
When you are ready, you can click “Run selected test”. As before, you can press any key to begin. The task will automatically stop when it finishes the set time.

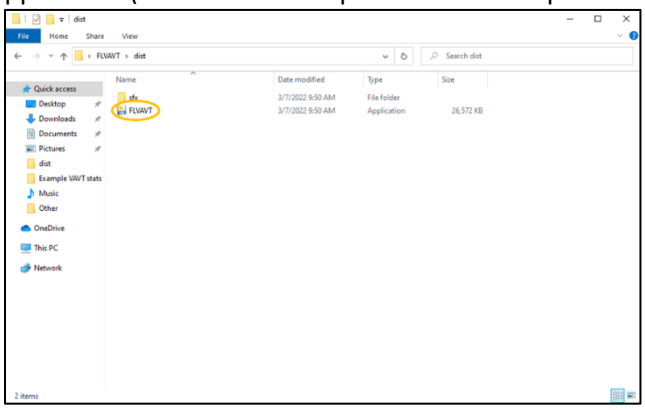




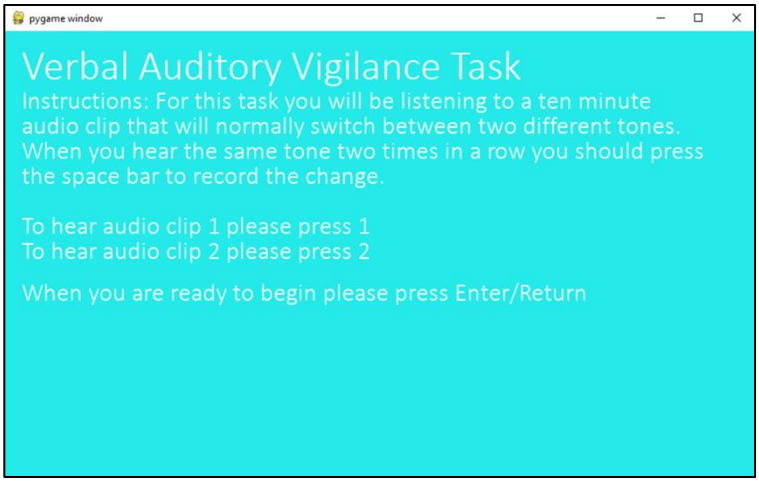
You can keep the PEBL software open since you will be coming back to it.

Step 4: Take the Subjective Ratings Survey
Click on this link and complete another short survey:
https://tamu.qualtrics.com/jfe/form/SV_9Fy9wtWNfmFsDhY

Step 5: Perform them VAVT
Open the “FLVAVT” application (as covered in Step 4 in the “Pre-Experiment” Instructions”).



Everything is now setup for you to complete the task session. If you need a reminder of the instructions, look back at the “Pre-Experiment Instructions document”.

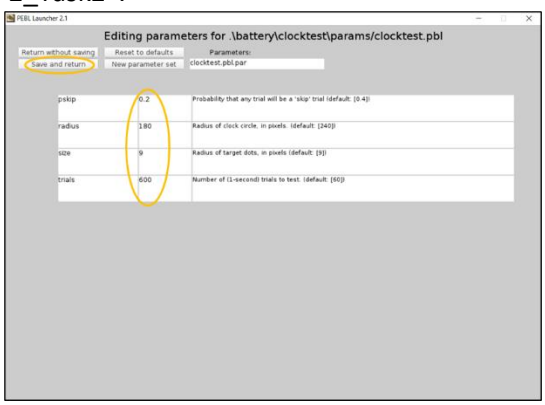


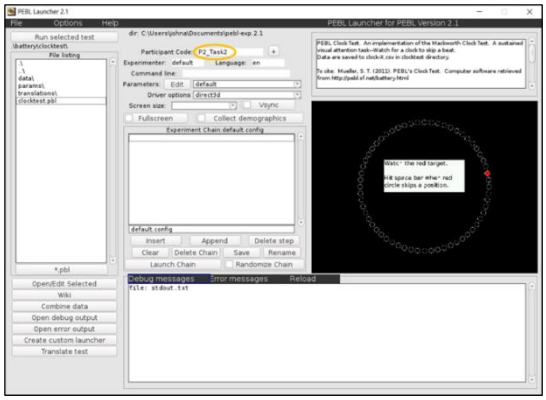
When you are ready to begin (and with the task window selected), press "Enter". The task should last approximately 10 minutes and will close on its own when this time has been reached.

Step 6: Take the Subjective Ratings Survey
Click on this link and complete another short survey:
https://tamu.qualtrics.com/jfe/form/SV_9Fy9wtWNfmFsDhY

Step 7: Perform the (PEBL) clock task – Part 2 of 2
This will be the second full session of the clock task. Navigate to the "Edit" parameters window as you have before and make sure the parameters are the same as those shown below (**0.2**, **180**, **9**, and **600**). Then click "Save and return".

You will now be back at the previous window. In the "Participant Code" box, type in "**P#_Task2**" with your participant number in place of the "#". For example, if you are participant 2, type in "P2_Task2".

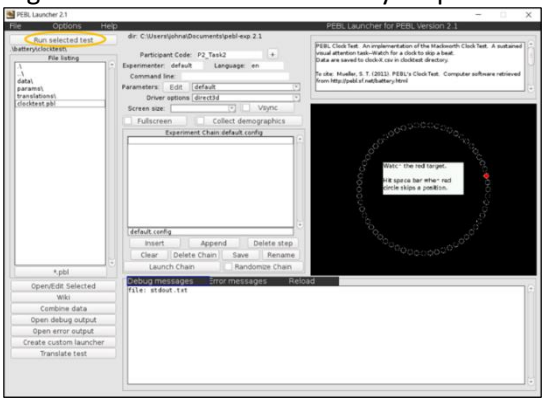


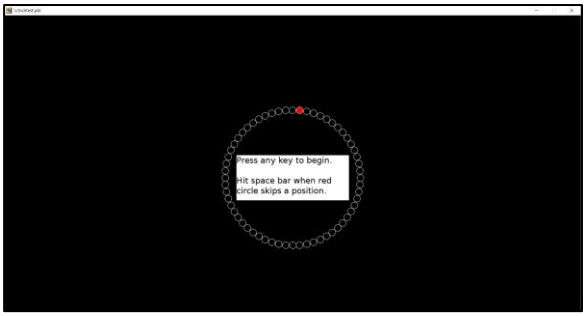


Again, this task session will last approximately 10 minutes. It is one of the most attention-critical parts of the experiment, so please eliminate any distractions/potential interruptions if

you have not already done so. Please try to do your best – as a reminder, up to an additional $5.00 can be earned based on your task performance.

When you are ready, you can click “Run selected test”. As before, you can press any key to begin. The task will automatically stop when it finishes the set time.

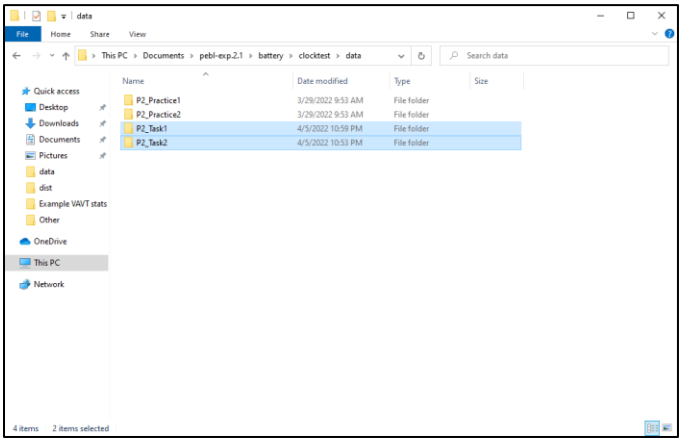




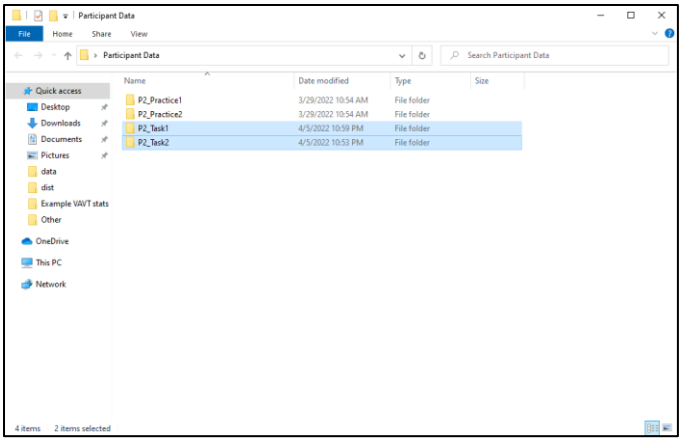
Step 8: Take the Subjective Ratings Survey
Click on this link and complete another short survey:
https://tamu.qualtrics.com/jfe/form/SV_9Fy9wtWNfmFsDhY

Step 9: Find and save (PEBL) clock task data in new location
Now you need save your clock task data in a new location. Find the “data” folder (as covered in Step 3 in the “Pre-Experiment” Instructions”).

Once you get in the “data” folder, you should see two folders which contain your task data.

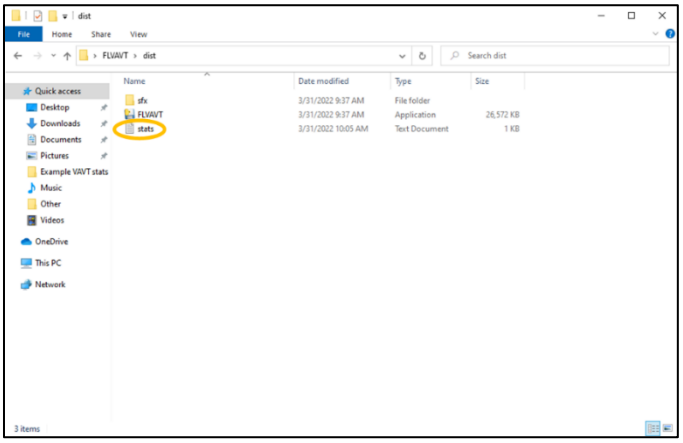


Copy these folders and then paste them in the “Participant Data” folder found on the desktop.

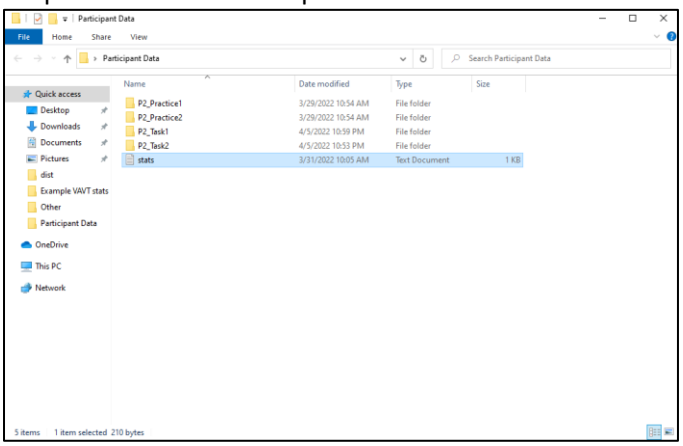


Step 10: Find and save VAVT task data in new location

Go to the “dist” folder (location covered in Step 4 in the “Pre-Experiment” Instructions”) and find the “stats” file.



Copy this file and then paste it in the “Participant Data” folder found on the desktop.



Summary of Steps:

Step 1: Take the Demographic and Work Information Survey
Step 2: Take the Start of Experiment Subjective Ratings Survey
Step 3: Perform the (PEBL) clock task – Part 1 of 2
Step 4: Take the Subjective Ratings Survey
Step 5: Perform the VAVT
Step 6: Take the Subjective Ratings Survey
Step 7: Perform the (PEBL) clock task – Part 2 of 2
Step 8: Take the Subjective Ratings Survey
Step 9: Find and save (PEBL) clock task data in new location
Step 10: Find and save VAVT task data in new location

If you have completed all the above steps, then you have finished the experiment. The research team will be reviewing your performance data and then following up with your participation compensation.

Thank you for participating!

APPENDIX K

DEMOGRAPHICS AND WORK INFORMATION SURVEY

Demographics and Work Information

1 Please enter your participant number.

_____

2 Please enter your age.

_____

3 Please select your gender.

Male

Female

Other _____

4 Is English the language you know best?

No

Yes

5 Please select your highest education completed.

Some high school

Graduated high school (or GED)

Some community college and/or trade school

Graduated community college and/or trade school

Some 4-year college

Graduated 4-year college

Some graduate school

Graduated master's degree

Graduated PhD or professional degree

6 Please answer the following questions about your work. This can include any jobs you have and/or schoolwork (classes, research, etc.) if you are a student.

7 Overall, is your work more physical or mental?

More physical More mental

8 Overall, is your work more repetitive or more variable?

More repetitive More variable

9 Overall, is your work more spatial (moving objects, navigating space, etc.) or more alphanumeric (dealing with words and/or numbers)?

More spatial More alphanumeric

10 Overall, is your work more visual (seeing) or auditory (hearing and/or speaking)?

More visual More auditory

11 Please answer the following questions about what tasks you have done today before participating in this study. These can be work related or not. For example, driving to this location is a task you can include.

12 Overall, were your tasks more physical or mental?

More physical More mental

13 Overall, were your tasks more repetitive or more variable?

More repetitive More variable

14 Overall, were your tasks more spatial (moving objects, navigating space, etc.) or more alphanumeric (dealing with words and/or numbers)?

More spatial More alphanumeric

15 Overall, were your tasks more visual (seeing) or auditory (hearing and/or speaking)?

More visual More auditory

16 How alert are you feeling now?

Not very alert Very alert

17 Have you had any food, beverages, or other substances (caffeine, etc.) that could affect your attention level?

Very little A lot

18 What is your current level of hunger?

Very hungry Very full

19 What is your current level of rest?

Exhausted Fully rested

APPENDIX L

START OF EXPERIMENT SUBJECTIVE RATINGS SURVEY

Subjective Ratings

1 Please enter your participant number.

_____

2 For the following questions, please answer based on what you have been doing today before this experiment.

Indicate your responses by sliding the bar.

4 **Mental demand**

How mentally demanding has your day been?

Very low Very high

5 **Physical demand**

How physically demanding has your day been?

Very low Very high

6 **Temporal demand**

How hurried or rushed has your day been?

Very low Very high

7 **Performance**

How successful have you been today in accomplishing what you have attempted?

Perfect Failure

8 **Effort**

How hard did you have to work to accomplish your level of performance?

Very low Very high

9 **Frustration**

How insecure, discouraged, irritated, stressed, and annoyed have you felt today?

Very low Very high

10 **Boredom**

How bored have you been today?

Very low Very high

11 **Motivation**

How motivated have you been today to do things?

Very low Very high

12 **Mind-wandering**

How much has your mind wandered today?

Very low Very high

APPENDIX M

SUBJECTIVE RATINGS SURVEY

Subjective Ratings

1 Please enter your participant number.

_____

2 Which task did you just complete?

Word task

Clock task

Sound task

3 For the following questions, please indicate your response by sliding the bar.

4 **Mental demand**

How mentally demanding was the task?

Very low Very high

5 **Physical demand**

How physically demanding was the task?

Very low Very high

6 **Temporal demand**

How hurried or rushed was the pace of the task?

Very low Very high

7 **Performance**

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

Perfect Failure

8 **Effort**

How hard did you have to work to accomplish your level of performance?

Very low Very high

9 **Frustration**

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

Very low Very high

10 **Boredom**

How bored were you during the task?

Very low Very high

11 **Motivation**

How motivated were you to do the task?

Very low Very high

12 **Mind-wandering**

How much did your mind wander during the task?

Very low Very high

APPENDIX N

REMOTE ASSOCIATES TEST (RAT) WORD GROUPS

	RAT Item
Practice	
1	cottage / swiss / cake
2	cream / skate / water
3	loser / throat / spot
Task	
1	show / life / row
2	night / wrist / stop
3	duck / fold / dollar
4	rocking / wheel / high
5	fountain / baking / pop
6	preserve / ranger / tropical
7	aid / rubber / wagon
8	cracker / fly / fighter
9	safety / cushion / point
10	cane / daddy / plum
11	dream / break / light
12	fish / mine / rush
13	political / surprise / line
14	measure / worm / video
15	high / district / house

16 sense / courtesy / place

17 worm / shelf / end

18 piece / mind / dating

19 flower / friend / scout

20 river / note / account

21 print / berry / bird

22 pie / luck / belly

23 date / alley / fold

24 opera / hand / dish

25 cadet / capsule / ship

26 fur / rack / tail

27 stick / maker / point

28 hound / pressure / shot

29 fox / man / peep

30 sleeping / bean / trash

APPENDIX O

REMOTE ASSOCIATES TEST (RAT) RESPONSE FORM AND KEY

RAT Task Response Form Participant #:_____

Practice

1. cheese

2. ice

3. sore

Number attempted: 30
Number correct: 30

Task

1. boat
2. watch
3. bill
4. chair
5. soda
6. forest
7. band
8. fire
9. pin
10. sugar
11. day
12. gold
13. party
14. tape
15. school OR court
16. common
17. book
18. game
19. girl
20. bank
21. blue
22. pot
23. blind
24. soap
25. space
26. coat
27. match
28. blood
29. hole
30. bag

APPENDIX P

NEW AGGIE INFORMATION HELPLINE TASK QUESTIONS

1. What does gig ‘em mean? And do I need to hold my thumb up when I say it?
2. What is a typical class like? I’ve seen movies where classes take place in these huge auditorium-like classrooms and the students just sit there and listen to the professor talk. Is that what they are like?
3. When can I get an Aggie ring and how expensive are they?
4. Is there a lot of homework and is it very difficult? How can I get help if I do not understand it?
5. How do I get a student ticket to a football game, and how much do they cost?
6. What are some tips for studying? Do study groups seem to help you?
7. What will I use my student ID card for? Do I need to carry it with me all the time?
8. What are the yell leaders? Do you try out for this position?
9. What are some fun things to do outside of school?
10. In high school I really liked history, but I was best at biology. What is your advice on deciding on a major?
11. What is the 12th man? Does it only have to do with football?
12. Do you recommend that I try to work a part-time job while I am in college? My family is helping me out with some of my expenses, but I heard it helps to have some extra spending money.

13. I know that Texas A&M is a large university, so it can be hard to get to know people. What are some student organizations I could try out?
14. What is the corps of cadets? Are these the students who want to go into the military?
15. What is midnight yell? Do I need a ticket to attend this?
16. What is the RELLIS campus and why is it called that?
17. Do you recommend getting a meal plan to eat at the cafeteria?
18. What is the bonfire that everyone talks about?
19. Are there any classes you recommend I try to take even if they aren't part of my major?
20. What is the silver taps ceremony? Is it just for the corps of cadets members?
21. What is the school's mascot? I've seen pictures of a dog, but also a drill-sergeant looking character.
22. What is the easiest way to register for classes? Can I do it all online?
23. What is the Big Event about? Is it required for a student?
24. When do people know when to say "whoop"?
25. What is a typical day like for you as a student?