Boredom in the Workplace: A new look at an old problem

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Precis: This article reviews historical and recent efforts in boredom research and related fields. It introduces a systems-based framework, called the Boredom Influence Diagram, that describes various elements of boredom and their interrelationships. Areas for future reseach are highlighted including experimental and task design considerations.

Abstract

Objective: This article reviews historical and more recent efforts in boredom research and related fields. A framework is presented which organizes the various facets of boredom, particularly in supervisory control settings, and research gaps and future potential areas for study are highlighted. **Background:** Given the ubiquity of boredom across a wide spectrum of work environments, exacerbated by increasingly automated systems which remove humans from direct, physical system interaction and possibly increasing tedium in the workplace, there is a need to not only better understand the multiple facets of boredom in work environments, but to develop targeted mitigation strategies. **Method:** To better understand the relationships between the various influences and outcomes of boredom, a systems-based framework, called the Boredom Influence Diagram, is proposed that describes various elements of boredom and their interrelationships. **Results:** Boredom is closely related to vigilance, attention management, and task performance. This review highlights the need to develop more naturalistic experiments that reflect the characteristics of a boring work environment. **Conclusion:** With the increase in automation, boredom in the workplace will likely become a more prevalent issue for motivation and retention. In addition, developing continuous measures of boredom based on physiological signals is critical. **Application:** Personnel selection and improvements in system and task design can potentially mitigate boredom. However, more work is needed to develop and evaluate other potential interventions.

Key Words**:** boredom, automation, distraction, monotony, monitoring, fatigue, workload

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I. Introduction

As early as the 19th century with the pending industrial revolution, Nietzsche (1878) warned that a machine culture would cause boredom for workers, resulting in human "play" at work. More than 130 years later, the news is replete with examples of just such a phenomenon. In 2009, during the enroute portion of a flight, two Northwest pilots reportedly were distracted by their laptops causing them to overfly Minneapolis by 90 minutes ("Northwest Airlines Flight 188," 2009). In 2011, an air traffic controller and a supervisor were suspended after it was discovered that the controller was watching movies in the early morning hours under reported light traffic conditions ("Movie-watching air traffic controller suspended," 2011). While ultimately distraction was the direct cause of operator misbehavior in these cases, the under-stimulating low task load i.e., boring, environment was a clear contributing factor.

Boredom and associated serious negative consequences have been reported across many other high risk settings including unmanned aerial vehicle operation (Thompson et al., 2006), process control plant supervision (Sheridan, Vámos, & Aida, 1983), train engineers (Haga, 1984), train drivers, and professional truck drivers (Dunn & Williamson, 2011; Oron-Gilad, Ronen, & Shinar, 2008), as well as anesthesiologists (Weinger, 1999). In boring environments where task load is low, typical in highly automated supervisory control environments, operators often find other tasks to help them sustain some level of attention and in many cases, simply to help them stay awake. With a global push to introduce more automation and autonomy into numerous safety-critical work environments, (e.g., driverless cars, positive train control in rail, and completely automated mines), boredom will likely be a growing problem.

While boredom in safety-critical settings is of obvious concern, it is also pervasive across more benign office work environments, often with such negative consequences as absenteeism and poor retention (Fisher, 1993).The Internet is replete with articles, blogs, and forums providing advice on how to survive and cope with a boring job. New social media sites such as glassdoor.com and indeed.com have emerged that allow employees the ability to anonymously rate their work environment, and comments such as "quite boring work environment with a lot of overtime," and "satisfactory but boring" are commonplace. In 2006 in the UK, 2,113 college graduates aged 21 to 45 were surveyed about workplace boredom, with 61% reporting boredom due to the lack of a challenging job. Those in administrative and manufacturing jobs reported the highest boredom, while healthcare workers and teachers reporting the least boredom ("Teaching 'the least boring job'," 2006). Boredom in the workplace has been identified as an important issue in organizational research (Fisher, 1993; Loukidou, Loan-Clarke, & Daniels, 2009).

Research has shown that boredom is often associated with significant health problems. Boredom has been linked to premature death due to cardiovascular disease(Britton & Shipley, 2010), and has been given as a primary reason for recreational drug use (McIntosh, MacDonald, & McKeganey, 2005). Boredom proneness has been linked to increasing risk of anxiety and depression (Sommers & Vodanovich, 2000; Vodanovich, Verner, & Gilbride, 1991), as well as substance abuse (Farmer & Sundberg, 1986; LePera, 2011) and eating disorders (Abramson & Stinson, 1977).

Given the ubiquity of boredom across a wide spectrum of work environments, exacerbated by increasing automated systems and advanced technologies (Nietzsche's forewarned "machine culture"), which remove humans from direct, physical system interactions and possibly increasing tedium in the workplace, there is a need to not only better understand the multiple facets of boredom in work environments, but to develop targeted mitigation strategies. Towards those ends, this article reviews historical and more recent efforts in boredom research and related fields, and specifically focuses on boredom in work environments in the presence of increasing automation. To better understand the relationships between the various influences and outcomes of boredom, we propose a systems-based framework that describes various elements of boredom and their interrelationships.

II. A Systems View of Boredom – the Boredom Influence Diagram (BID)

In research settings, there is still debate as to the exact definition of boredom. In the late 1920s, boredom was thought to stem from inadequate vascular responses (McDowall & Wells, 1927). A decade later, Barmack (1937) defined boredom as a state of internal conflict, caused by inadequate motivation and a desire to remove oneself from a task. O'Hanlon (1981) defined boredom as a psychophysiologic state resulting from prolonged periods of monotonous stimulation. More recently, researchers have generally gravitated to labeling boredom as an affective, and thus subjective, state of low arousal and dissatisfaction caused by a lack of interest in an inadequately stimulating environment (Fisher, 1993; Mikulas & Vodanovich, 1993; Pattyn, Neyt, Henderickx, & Soetens, 2008).

In his circumplex model of affect, Russell (1980) places boredom roughly halfway between misery and sleepiness. Thackray (1981) reviewed previous studies and concluded that boredom or monotony does not cause stress. Rather, it is the coupling between monotony and a need to maintain high levels of alertness that elicits considerable stress. Hill and Perkins (1985) broke down boredom into a cognitive component of subjective monotony and an affective component of frustration. Focusing more on the underlying mental processes, Eastwood et al. (2012) defined boredom as the aversive state that occurs when one fails to engage attention and participate in satisfying activities.

In the study of optimal experience, boredom is regarded as a mental state resulting from a low challenge level as compared to individual skill level and the lack of intrinsic motivation (Csikszentmihalyi, 2014). We could argue that motivation is part of the cognitive component of boredom, because it affects whether an individual perceives the task as boring or interesting. The multidimensional aspect of boredom highlights the fact that boredom is often linked with other physical and cognitive states such as fatigue (Desmond & Hancock, 2001) and vigilance (Eastwood et al., 2012), as well as individual traits such as motivation and personality.

In an attempt to clarify the multidimensional causes, effects, and interactions of boredom and to coherently organize this review, we propose the influence diagram in Figure 1. To our knowledge, the Boredom Influence Diagram (BID) is the first such systems representation of boredom and its multidimensional attributes. The concepts and interactions shown in this model represent fields of research across many different disciplines.

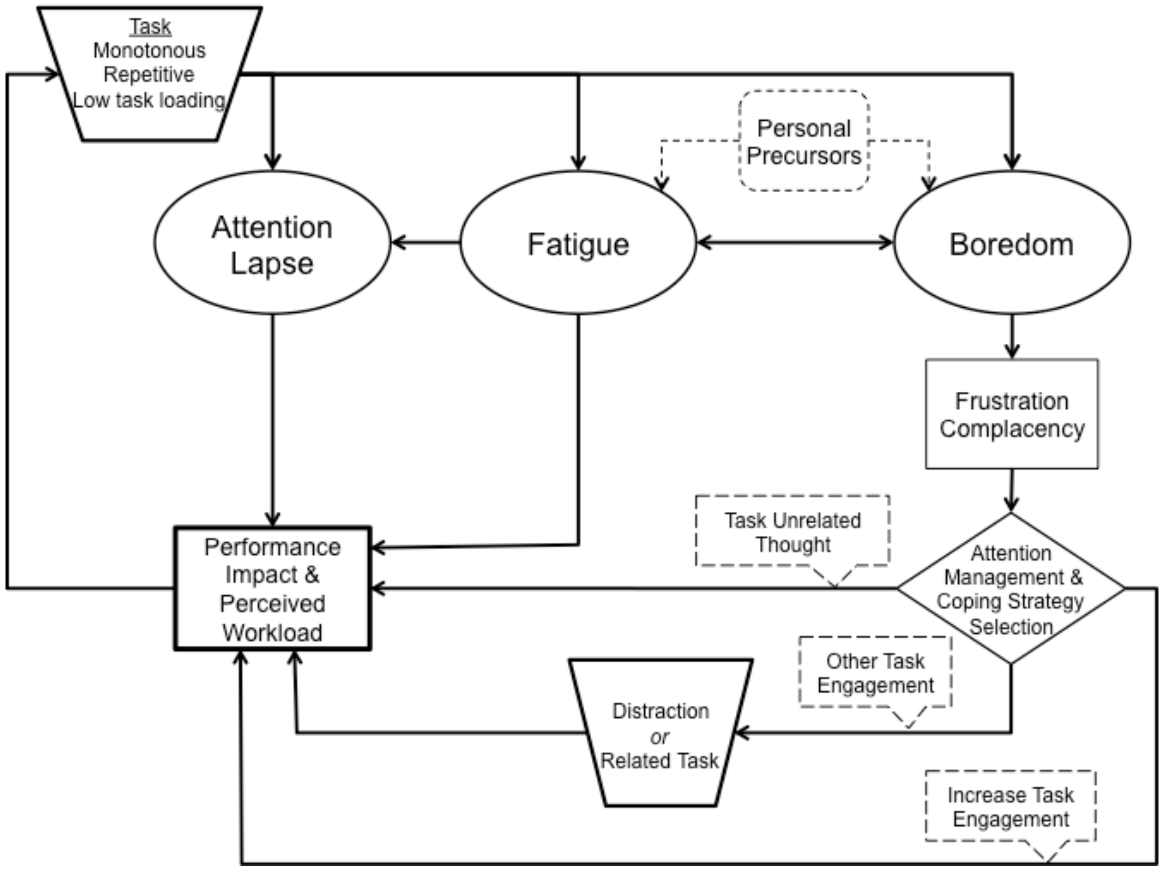

Figure 1: Boredom Influence Diagram

As the purpose of this review is to focus on boredom, we discuss each of the conceptual elements through that lens. The BID framework does not imply cause and effect relationships. Rather, each directional link represents interactions or influences that have been demonstrated or hypothesized in the literature. To begin to understand this diagram, each component will be reviewed and discussed in the following sections.

Defining Boring Tasks

As seen in the trapezoid in the upper left corner of Figure 1, we begin by defining those tasks likely to be perceived as boring. We include monotonous and repetitive tasks in work environments that require constant attention (such as an assembly line task), as well as low task loading scenarios, such as an air traffic controller watching a screen at 2:00 am in the morning, waiting for an aircraft to enter his or her sector. It is important to note the difference between task load (the demands required by the work environment) and workload (the subjective interpretation of task load by an individual), as workload sometimes can be high in monotonous or repetitive tasks, even with low task demand (Warm, Parasuraman, & Matthews, 2008) .

A significant number of previous studies and reviews of boredom in the workplace have focused primarily on environments that include repetitive and monotonous motor tasks such as assembly line production (O'Hanlon, 1981; Smith, 1981), which is not surprising given the rise of the industrial mass production complex over the first half of the 20th century. More recent studies have shown that boredom occurs in mentally demanding environments that require constant attention (Becker, Warm, Dember, & Hancock, 1991; Dittmar, Warm, Dember, & Ricks, 1993; Prinzel & Freeman, 1997; Sawin & Scerbo, 1994, 1995; Scerbo, Greenwald, & Sawin, 1993). However, there are markedly fewer studies investigating those perceived boring environments where humans are passively monitoring complex systems, waiting for a problem to occur.

As automation has become more prevalent across various work domains, there has been a clear shift away from human manual work on production lines or in direct manual control of vehicles to those environments where humans are supervising automated processes, e.g., in automotive manufacturing plants, robots do the bulk of production line work and in commercial aircraft, pilots spend increasingly amounts of time supervising the autopilot which is actually flying the plane. This increase in automation, however, has not alleviated the boredom associated with these tasks. In many cases, it has exacerbated it, a common phenomenon when more automation is inserted in any system (Bainbridge, 1983).

So the introduction of more automation in complex systems means that boredom once caused by monotonous and repetitive tasks is now shifting to boredom caused by low task loading in the monitoring of such systems. And while there is significant previous work in the relationship of boredom to monotonous and repetitive environments, there is a paucity of research on work environments that address human behavior and possible mitigations in environments with almost nothing to do, both with and without highly automated systems (Fisher, 1993).

While monitoring a radar or security screening display is very similar to the monotonous vigilance tasks of signal discrimination used in many research settings, monitoring complex automated systems have several different characteristics. Instead of discriminating an event as signal or non-signal repeatedly, people monitoring an automated system have more ambiguous target signals to look for, with typically much longer times between the occurrence of an event. In addition, successful task completion in a complex automated system typically requires much higher situation awareness and problem solving skills.

It should be noted that boredom is a subjective phenomenon, the onset of which is unique to each individual that experiences it. A person's perception of the task at hand may lead to complacency and cognitive disengagement from the task if the task is perceived to be unimportant or uninteresting. The affective component of boredom reflects a person's emotional perception of the task at hand. These feelings may include frustration, dissatisfaction, or melancholy. For example, boredom may be induced solely as an emotion by asking participants to do nothing (Wilson et al., 2014) or watch uninteresting videos (Merrifield & Danckert, 2014).

We propose in BID (Figure 1) that three possible behavioral states can occur when a person engages in a task that is monotonous, repetitive, or low task loading: 1) The inability to sustain attention (which we call Attention Lapse), 2) Fatigue, and/or 3) Boredom (represented by ovals in Figure 1). These are not mutually exclusive, in that a person could experience one or more of these states simultaneously. Each of these outcomes is discussed in detail in the next sections.

Attention Lapse

In low task load, highly automated environments, the first likely detectable behavioral outcome for an operator is a lapse in sustained attention, or an ability to maintain “vigilance”. Vigilance, by definition, is “a state of readiness to detect and respond to certain small changes occurring at random time intervals in the environment" (Mackworth, 1957). Typical vigilance tasks, therefore, are naturally repetitive and, at times, could be monotonous and considered to be boring. The vigilance decrement, the decline in performance efficiency over time, is commonly measured in terms of the rate of the correct detection of critical signals and slowed reaction time (Parasuraman, 1986).

Monotonous and repetitive tasks have been shown to influence vigilance in a wide range of activities (Parasuraman & Davies, 1977), commonly resulting in increases in vigilance decrements, manifested in negative impacts on task performance. The vigilance decrement is commonly measured in terms of missed signals, longer reaction times, and generally poorer performance than can reasonably be expected (Davies & Parasuraman, 1982). Vigilance decrements have been demonstrated many times in domains such as aviation (Schroeder, Touchstone, Stern, Stoliarov, & Thackray, 1994; Wiggins, 2011), medical monitoring (Weinger & Englund, 1990), driving (Thiffault & Bergeron, 2003) and rail operations (Haga, 1984).

Many studies have tried to explain the mechanism of the vigilance decrement, including mental fatigue (Boksem, Meijman, & Lorist, 2005; Warm, Parasuraman, et al., 2008), failure in executive control and attention management (Grier et al., 2003), as well as boredom (Scerbo, 1998a). None of these factors can fully explain the vigilance decrement. Instead, they are interconnected as illustrated in Figure 1. As suggested by Scerbo (1998a), boredom could be the driver for shifting attention away from the primary task, and constantly combating boredom to stay alert could result in stress and fatigue.

Fatigue

Fatigue can be classified in terms of physiological fatigue or cognitive fatigue, although there is not a crisp defining line between the two, in that the perception of fatigue often drives the interpretation of physical fatigue (Matthews, Hancock, Desmond, & Neubauer, 2012). In a task that involves repetitive gross motor movements, physiological fatigue is common as the body uses its energy reserves. Cognitive fatigue, on the other hand, is generally related to weariness related to depletion of information processing assets (Kahneman, 1973; Warm, Matthews, & Finomore, 2008), reduced motivation (Lee, Hicks, & Nino-Murcia, 1991), or stress (Aaronson et al., 1999).

In tasks that are stressful, such as monotonous tasks described previously (Warm, Parasuraman, et al., 2008), cognitive fatigue will continue to increase as the task duration increases. Fatigue can also be considered as an aggregation of physiological and cognitive fatigue, becoming a sustained feeling of exhaustion that may decrease the ability of a person to conduct physical or mental tasks (Carpenito-Moyet, 2006).

There is a distinction between active fatigue and passive fatigue. Active fatigue is derived from continuous and prolonged task-related perceptual-motor adjustment. In contrast, passive fatigue happens in tasks that require system monitoring with either rare or even no overt perceptual-motor response requirements (Desmond & Hancock, 2001). In driving, passive fatigue could happen with high levels of vehicle automation, which could reduce driver alertness and increase crash probability (Saxby, Matthews, Warm, Hitchcock, & Neubauer, 2013). Although both passive fatigue and boredom happen under low workload, they reflect different constructs of human cognition. Passive fatigue focuses more on the resource depletion aspect, while boredom reflects the affective state.

Boredom

While vigilance decrements can be measured and cognitive fatigue induced in people, boredom may be introduced in tasks that do not result in vigilance decrements or cognitive fatigue (Hitchcock, Dember, Warm, Moroney, & See, 1999; Merrifield & Danckert, 2014). Boredom has been described as having two components: a cognitive component and an affective component (Stager, Hameluck, & Jubis, 1989). Hill and Perkins (1985) defined the cognitive component as how a person perceives and constructs the task. The affective component comes from the conflict between the inadequate stimuli and the inability to be stimulated in the current environment (Barmack, 1939; Fenichel, 1951; Hill & Perkins, 1985). People are constrained in a boring environment and cannot escape, or they may try to look for new stimulus but fail. The affective state is the coexistence of stimulus-hunger and dissatisfaction, even frustration. In most work environments, such constraints come from production schedules, management policies, and work responsibilities.

Many studies show that vigilance decrement occurs after 20-30 minutes for a task that requires sustained attention (Wickens, Lee, Liu, & Gordon-Becker, 2011). It could take a shorter or longer time to observe a vigilance decrement depending on signal modality, signal salience, signal probability, temporal uncertainty, event rate, sleep loss, etc. (Davies & Parasuraman, 1982; Loh, Lamond, Dorrian, Roach, & Dawson, 2004; Warm, Finomore, Vidulich, & Funke, 2015). Similarly, boredom can develop as the novelty of a stimulus wears off or the lack of stimuli reaches a satiation point, exacerbated in work environments by the inability to seek new stimuli (Barmack, 1939; Scerbo, 1998a).

However, there is no consensus and very little research on the temporal aspects of boredom, such as how long it takes to achieve a state of boredom and what conditions or individual differences affect the time at which a state of boredom is achieved. For example, in a study where passive fatigue was introduced by automated driving, task engagement decreased over time, though level of fatigue and boredom were not explicitly measured (Saxby et al., 2013). Moreover, while the vigilance decrement (Warm, Dember, & Hancock, 1996) is fairly well established across a large cross section of participants and domains, given the subjective nature of boredom, it is not clear if there are any repeatable assumptions that could be made about the onset time and duration of boredom, particularly as these relate to different subpopulations.

The parallel representation in Figure 1 of attention lapse, boredom, and fatigue also highlights the experimental difficulties in isolating the effects of one state from the other. To effectively study just boredom, we hypothesize that this may not be possible unless the effects of the loss of vigilance and fatigue can be controlled for (either experimentally or statistically). Because it is unlikely that the effects of boredom could be cleanly isolated from the vigilance decrement in the first 30 minutes of a study requiring sustained attention on a task, any experiment that tries to measure boredom in this time period is inherently confounded. This speaks to the need for better boredom assessment strategies, which is discussed further in a later section.

Personal Precursors

Since individual traits such as motivation and sleep habits can influence the ability to maintain vigilance and combat fatigue and boredom, they are shown in Figure 1 as personal precursors. Given that significant previous research has been devoted to the influence of individual differences on vigilance (Reinerman-Jones, Matthews, Langheim, & Warm, 2010; Shaw et al., 2010; Szalma & Matthews, 2015; Thackray, Jones, & Touchstone, 1974) and fatigue (Lal & Craig, 2001; Matthews et al., 2012; Van Dongen & Belenky, 2009), this discussion will focus on the relationship between individual differences and boredom. Boredom proneness relates to an individual's ability to manage sustained attention tasks (Farmer & Sundberg, 1986). Some individuals are more susceptible to boredom than others when facing the same situations that lack external stimuli. Boredom proneness has been positively associated with inpatient behavior, distraction, sensation seeking, impulsiveness, and work performance (Dahlen, Martin, Ragan, & Kuhlman, 2005; Kass & Vodanovich, 1990; Vodanovich et al., 1991).

In terms of personality traits, extraversion has been associated with boredom proneness (Ahmed, 1990), but high levels of conscientiousness have shown the opposite effect (Mkrtchyan, Macbeth, Solovey, Ryan, & Cummings, 2012). Other personality traits of those people able to more effectively cope with boredom include the ability to spend time alone, high measures of attentional capacity, and low formal diagnostic indices of psychopathology (Hamilton, Haier, & Buchsbaum, 1984).

The relation of personality and boredom proneness has been examined in a few studies (Culp, 2006; Shaw et al., 2010). In one effort attempting to examine the impact of individual differences on vigilance performance more holistically, a factor analysis was conducted based on measures of personality, cognitive–energetic scales, fatigue vulnerability, boredom proneness, sleep quality, cognitive dysfunction, abnormal personality, impulsiveness, cognitive ability, stress states, and coping (Shaw et al., 2010). Four key factors were determined to be cognitive disorganization, heightened experience (defined by unusual experiences, sensation-seeking, and low internal boredom), sleep quality, and impulsivity.

In addition, experience, age, intellectual capacity, cultural background, and gender have all been suggested as contributors to the perception of boredom (Fisher, 1993; Vodanovich & Kass, 1990a). Males tend to exhibit more proneness towards boredom than females (Sundberg, Latkin, Farmer, & Saoud, 1991), and older people tend to be less susceptible to boredom(Vodanovich & Kass, 1990a), although neither of these results are universally found across studies.

A person's interest or motivation in assigned workplace tasks also likely has an impact on an individual's state of boredom (Fisher, 1993; Sawin & Scerbo, 1995). In one study, individual interest in simple tasks was manipulated by asking participants to set higher goals, resulting in improved performance with reduced boredom (Locke & Bryan, 1967). However, given the subjective nature of boredom, individuals will differ in their level of interest in a specific activity, and some can report extreme boredom and others sufficient interest even in an identical environment (Fisher, 1993). Boredom has been cited as a direct cause for recruitment and retention issues for the US Air Force's Unmanned Aerial Vehicle (UAV) workforce (Cummings, 2008), which is problematic since such operators are highly skilled and take years to train.

The effect of boredom on work performance is not uniform for all individuals but rather depends on individual differences (Drory, 1982). Identifying who is more prone to boredom will be discussed more fully in a subsequent section on measuring and assessing boredom. It has been shown that high boredom proneness people perform poorly on sustained attention tasks (Malkovsky, Merrifield, Goldberg, & Danckert, 2012). In another study examining motivation and boredom, boredom-prone workers felt they were underemployed and received less organizational support, and in somewhat of a self-fulfilling prophecy, received lower performance ratings(Watt & Hargis, 2010) . This highlights a possible negative motivational feedback loop inherent in these systems.

Attention Management and Coping Strategy Selection

The last major section of the BID is the entry into the attention management and coping strategy selection phase, represented by a diamond in Figure 1. As exemplified by rail train drivers and truck drivers who reported that they listen to music or radio, talk to their co-drivers, eat or snack, and drink caffeine while driving to cope with monotony and boredom (Dunn & Williamson, 2011; Oron-Gilad & Shinar, 2000), operators will often seek out potentially distracting behaviors simply to stay engaged, although the impact on performance may be ineffective.

Just prior to the decision diamond representing boredom coping strategies, we have included the effects frustration and complacency, which could influence the coping strategy selected by an individual. While the tendency toward complacency could be considered a personal precursor, boring work environments can result in or exacerbate complacency.

Boredom leading to complacency is an established behavioral response in the aviation domain (Wiener & Nagel, 1988), which likely leads not only to immediate performance implications but also to long term retention concerns, especially in the presence of increasing automation (Parasuraman & Manzey, 2010). In addition, in many studies and surveys, people report that they find working in boring environments frustrating (Bruursema, Kessler, & Spector, 2011; Fisher, 1993; Loukidou et al., 2009; O'Hanlon, 1981), which likely leads to not only immediate performance implications but also long term retention concerns. It has been shown that that high boredom-prone individuals perform poorly on measures of sustained attention and show increased symptoms of attention deficit hyperactivity disorder ADHD and depression (Malkovsky et al., 2012). As a result, we propose frustration and complacency are responses that will likely affect the coping strategies selected by individuals. Since understanding operator coping mechanisms is of critical importance in system design, we explore how these boredom coping mechanisms can influence performance.

In terms of coping with a stressful task, one previous study proposed three strategies for coping with a stressful task environment including task-focused coping that attempts to formulate and execute a plan of action to deal with the source of demands directly, emotion-focused coping that attempts to deal with the stressor by changing one's feelings or thoughts about it, and avoidance coping by diverting attention away from the problem (Matthews & Campbell, 1998). Other research examining the effects of stress and high workload on human performance proposes that people cope with fatigue and excessive workload by reducing effort and lower their own performance standards (Hockey, 1997). A study on boredom in education identified three coping profiles of students: appraisers that try to change their own perspective of the situation, criticizers that believe they can change the situation by voicing their boredom, and evaders that simply try to avoid the boring setting by doing something else (Daniels, Tze, & Goetz, 2015).

Given this previous research, we propose that when faced with a perceived boring task, resulting behavioral changes can be abstracted into one of three categorical behaviors: 1) task unrelated thought, 2) other task engagement (also known as distraction), 3) changing task engagement. Task unrelated thought and other task engagement are avoidance coping strategies, which represent passive and active forms of shifting attention. For these states, attention is shifted away from the primary task much like the avoiders and evaders from the previous studies. Our categorization of changing task engagement is a task-focused coping strategy, in which attention is allocated towards the primary task. We elected not to include an emotion-focused coping strategy here because boredom itself is an affective state. These three coping strategies are discussed in more detail next.

Task Unrelated Thought

One way for operators to cope with boredom and associated frustration and complacency is through Task Unrelated Thought (TUT), also known as mind wandering, stimulus-independent thought, and daydreaming, which occurs when one's mind drifts "from a task toward unrelated inner thoughts, fantasies, feelings, and other musings (Smallwood & Schooler, 2006)." Daydreaming and thinking were frequently reported as strategies used to cope with boredom in life (Fisher, 1993; Harris, 2000). In a study of airline pilots serving in a monitoring role, it was observed that pilots devoted 43% of their available monitoring time to TUT, often when they felt their performance would not conspicuously suffer (Casner & Schooler, 2015). The basic implication of TUT is that a person may be physically present in a control environment, but is unable to remain cognizant of the control task at hand. This disengagement is the resulting effect of an endogenously generated distraction, created to cognitively engage the individual and limit the negative affect felt during low task loading.

TUT and self-generated thought are spontaneous processes and the default state of the individual. Based on brain imaging results, neuroscience research has found that the brain is more active at rest than in a range of explicit tasks, possibly because the brain is engaging in self-generated thought (Morcom & Fletcher, 2007). Several studies proposed that TUT reflects a failure in executive control (McVay & Kane, 2010; Thomson, Besner,

& Smilek, 2015). Instead of devoting attention to TUTs by choice, individuals need to execute explicit control to sustain active goal maintenance and to prevent TUTs. TUTs are considered as spontaneous processes (Christoff, Ream, & Gabrieli, 2004).

While TUT can occur in high workload environments, it is generally associated with under stimulating, low task load environments, and has recently been shown to be pervasive across all aspects of life (Killingsworth & Gilbert, 2010). TUT consumes attentional resources and reduces the attention devoted to the primary task (Smallwood & Schooler, 2006).

In one boring search task, a majority of participants exhibited task disengagement in the form of non-task-related mental activity (Pattyn et al., 2008). TUT has also been found to increase across the duration of a vigilance task, accompanied by a decrease in detection accuracy (Cunningham, Scerbo, & Freeman, 2000). Higher levels of automation allow for more TUT as shown in a flight automation study (Casner & Schooler, 2014). Thus, the performance impact of TUT on a particular task can be seen as negative when considering missed signals and increased reaction times, as individuals seem to be incapable of engaging in TUT and the task concurrently. It is important to note that TUT is a passive form of coping, in that one is usually not engaged in any physical activity or conversation.

Other Task Engagement

While TUT represents a passive form of task disengagement in perceived boring environments, engaging in tasks other than the primary task represents a more active form of task disengagement. People may seek stimulation intentionally from sources other than the primary task when they feel bored or they may be easily distracted by external activities in the environment. The previous examples of the Northwest pilots working on their laptops, causing them to overfly Minneapolis, and the air traffic controller watching a movie in the early morning hours are examples of such occurrences.

While such events can be seen as distractions, it is important to make the subtle distinction as to the source of the distraction. In the interruption recovery literature (John, Smallman, & Manes, 2005; Scott, Mercier, Cummings, & Wang, 2006), distractions are generally seen as exogenous events that cause an operator to shift attention from a primary to an intruding task. In low task load, boring environments, operators may seek stimulation from a possibly unrelated source, in effect seeking an interruption, and so in this context, the source of such distractions is endogenous and intentional.

As seen in Figure 1, we label these two basic types of ‘other tasks’ as Distraction or Related tasks. For example, in many process control plants, operators will often complete training modules during low task loading, so arguably they are somewhat distracted, but by a task that is related to their current job. However, operators in such environments also read magazines or newspapers, which is an unrelated task. How related versus unrelated distractions impact performance is an area that has received very little attention in research settings.

It is not clear whether such distractions in low task load environments always result in poor performance. For example, although talking on one’s cell phone while driving has been repeatedly shown to lead to driver distraction in high workload settings

(Patten, Kircher, Östlund, & Nilsson, 2004), little research has been done to examine possible positive benefits, such as when driving during long stretches of highway, particularly at night. Military truck drivers have reported cell phone use relieves some monotony experienced during long drives (Oron-Gilad et al., 2008) and thus a possible positive relationship between some distraction and relieving the negative impacts of boredom.

So while it is possible that distraction could reduce boredom during a task, this likely only leads to positive performance benefits when the task requires low levels of attention, such as in monitoring an automated system for an alert. When the task requires more substantial engagement of attention such as what is needed to complete monotonous or repetitive tasks, distraction will not likely relieve boredom (Fisher, 1998).

In terms or mitigating the negative affects of boredom, it has been proposed that a secondary task can be strategically embedded in the primary task setting in order to decrease boredom and increase capability and concentration, which would ultimately increase performance and safety (Atchley & Chan, 2011). In one driving study, it was found that introduction of a concurrent verbal free association task improved lane-keeping performance and lowered steering wheel deviations in some conditions during prolonged driving (Atchley & Chan, 2011). In another diving study, Oron-Gilad et al. (2008) compared answering trivia questions, a choice reaction time task, a working memory task, and listening to music as secondary tasks to help drivers stay alert. It was found that the trivia task prevented driving performance deterioration and increased alertness, while the working memory task was detrimental to driving.

However, this strategy of introducing a secondary task must be used with caution. The attention requirements of the primary and secondary tasks must be carefully evaluated to avoid any negative impact. If the secondary task requires little cognitive effort, it could result in positive effects such as reducing boredom. However, in more complex cognitive engagement tasks, such embedded secondary tasking may cause overload and result in decreased performance.

Changing Task Engagement

The last possible coping strategy category, changing task engagement, is another area that has received little attention in the literature. High level of task engagement is characterized by high energetic arousal, task interest, success motivation, and concentration (Matthews, Warm, Reinerman-Jones, et al., 2010). Behaviorally, operators become aware that the task load is low, and interact with the system to change their task load to stave off any negative effects of boredom. For example, night watchmen in charge of monitoring several cameras may constantly manually pan and zoom in order to stay alert. Changing the primary task engagement includes accessing task-related imagination, refocusing attention on the task, and increasing or changing the complexity of the task.

Task-related imagination turns the primary task into a game or mental cinema, which may increase the degree of intrinsic interest in the task and reduce boredom (Eastwood et al., 2012). In contrast to TUT which diverts attention to unrelated thoughts, the imagination is engaged to consider the task at hand. Further, this may improve task performance by facilitating absorption thereby attenuating the experience of attention failure, effort, and boredom, which would then promote successful engagement with the current task (Csikszentmihalyi, 1978; Eastwood et al., 2012).

A related technique called gamification has been used in education settings by including game-like elements to engaged bored students (Barata, Gama, Jorge, & Goncalves, 2013). Some have proposed applying gamification for driving (Schroeter, Oxtoby, & Johnson, 2014), but its utility remains untested in this setting. In one process control study, allowing operators to play a nuclear power optimization game in parallel with a low workload primary task did not improve performance but neither did it degrade it (Thornburg, Peterse, Liu, & Oman, 2011).

Another method to change task engagement is to simply notify or alert the operator periodically so that he/she could refocus attention to the task. One study has shown that such a strategy can be useful for operators prone to boredom and distracted for a considerable amount of time (Mkrtchyan et al., 2012). Others have suggested that using biofeedback (such as using EEG to monitor physiological processes) and displaying this information to an operator in real-time can potentially alert an operator to refocus. One study showed that TUTs can be reflected in EEG power band ratios in the intervals immediately preceding and following the subject's report of a TUT (Cunningham et al., 2000). It has been proposed that such feedback could be beneficial in stimulating cognitive activity and reducing boredom during monitoring tasks (Alves & Kelsey, 2010; Frederick-Recascino & Hilscher, 2001).

The third form of changing task engagement is to modify the complexity or requirement of the primary task. This could be initiated either by human activity or by the system. In the driving scenario for example, drivers may try to maintain some level of arousal by using adjustments in speed to change the task difficulty (Fuller, 2005). They may increase speed as a response to under stimulation, especially young male drivers (Heslop, Harvey, Thorpe, & Mulley, 2009). In a nuclear power plant example, human operators have the option to examine individual systems components in more detail from the control console. UAV operators can elect to bring up new displays through various menus to consider new sources of information.

However, the system could be designed to increase task requirements in order to increase operator engagement. In one air traffic control monitoring study, task engagement was increased by requiring the controller to click on each aircraft as it entered the airspace, which mitigated the vigilance decrement after the operators were sufficiently trained for the task (Pop, Stearman, Kazi, & Durso, 2012). Task engagement can also be adjusted dynamically by varying task difficulty according to the measurement of operator status as revealed through functional near-infrared spectroscopy (fNIRS) signals. Afergan et al. (2014) used such signals to increase operator awareness and reduce errors. In video game design, increasing task engagement by adjusting difficulty levels and skill requirements over time is a common method to avoid boredom as well.

Changing or increasing task engagement may have positive or negative influence. Obviously, seeking stimulation by speeding up raises safety concerns during driving. On the other hand, some cases in European cities show that creating a shared space between cars, bikers, and pedestrians on the road could surprisingly increase safety (Hamilton-Baillie, 2008). Although the underlying mechanism is not entirely clear, one possible reason is that shared space forces drivers to devote more attention and effort into driving, reducing the tendency to speed when they feel under stimulated.

Whether increasing task engagement could improve performance also depends on the level of additional cognitive demands placed on the operator. In the air traffic control monitoring study mentioned earlier (Pop et al., 2012), engaging the operator by requiring the controller to click on each aircraft as it entered the airspace alleviated the vigilance decrement after practice. However, when the engagement task required increasing attention, the vigilance decrement could not be eliminated because the engagement task was competing with the primary task, resulting in operator cognitive overload.

Another concern that arises when operators elect to increase their primary task engagement by interacting more with their system is whether that system is robust to the increased interactions. For example, in one study where participants performed a decentralized multiple UAV control task, operators that interacted too frequently with a system harnessing optimization algorithms could actually drive the system to a sub-optimal state (Cummings, How, Whitten, & Toupet, 2012). So in some cases it is possible for an operator to attempt to alleviate boredom by interacting with the system, which could ultimately result in degraded system performance.

It should be noted that all three of these coping strategies (engaging task-related imagination, refocusing attention on the task, and increasing or changing the complexity of the task) could all be present for a single operator over the course of a single shift in a low task or monotonous environment. More research is needed to both observe if and how people vary these strategies to combat the negative effects of boredom and how such application of strategies can either improve or degrade overall systems performance.

Performance Impact and Perceived Workload

The final block in the BID depicted in Figure 1 is that of Performance Impact and Perceived Workload, which is clearly a critical outcome. Regardless of the task type or the coping strategy, the BID in Figure 1 demonstrates that lapses in attention, fatigue, and boredom can occur in parallel, ultimately influencing system performance and operator workload. It should be noted that these attentional lapses could be both episodic, as well as persistent states.

The influence of fatigue on performance is well documented (Krueger, 1989). For example, operators of UAVs in long duration missions will commonly rate their feeling of fatigue to be very high (Chappelle et al., 2014). Such affective states, particularly negative, can greatly influence human performance (Norman, 2004), and in the case of UAV operations, cognitive fatigue has been shown to result in slower responsiveness and reduced task performance (Thompson et al., 2006).

Moreover, loss of vigilance can cause delayed response, missed signals, and increased false alarms. Boredom and individual coping strategies affect performance indirectly by changing attention allocation. Smallwood et al. (2004) suggest that although high levels of TUT can happen together with increased errors in sustained attention tasks, TUT is not the direct cause of performance decrement. In general, fatigue, boredom, and loss of vigilance result in a decrease in task performance.

What is not explicitly represented in Figure 1 in terms of performance impact but likely is significant is the temporal factor. For example, if some operators tend to cope with boredom by increasing their own workload either through introducing endogenous tasking or distractions, are they then more prone to fatigue over time, which could influence complacency and/or frustration? How can we better model the temporal influence of boredom and passive fatigue in low task environments? We posit these questions as areas for future investigation, as there is little in the current literature to address the temporal aspects of boredom.

In addition to performance, perceived workload is also affected by task demand, fatigue, and boredom. It has been shown that workload is the highest under active fatigue with difficult manual driving, and lowest under passive fatigue with automated driving (Saxby et al., 2013). In several studies with vigilance tasks requiring participants to discriminate between signals, monotonous vigilance tasks are often rated as high in workload and stressful (Finomore, Shaw, Warm, Matthews, & Boles, 2013; Warm et al., 2015; Warm, Parasuraman, et al., 2008). Thus workload is influenced by task demand, which can be correlated with monotony of the task and the degree of automation. However, workload and boredom can be manipulated independently. In a vigilance task, cueing the arrival of a signal can decrease workload while keeping the boredom level of task unchanged (Hitchcock et al., 1999).

This introduction and discussion of the BID is useful in understanding the influence, interactions, and performance implications of working in a boring low task loading and/or monotonous environment. However, one critical component to making such a framework useful is identifying those people, processes, and coping strategies that lead to better outcomes in such an environment by assessing and measuring the impact of these different aspects. The next section will outline commonly used assessment strategies and measures for operators working in boring low task load and/or monotonous environments, with an emphasis on those environments where automation plays a significant role.

III. Measuring and Assessing Boredom

Due to its association with many negative emotions and behaviors, past attempts have been made to assess boredom and people's proneness to boredom, but the experimental research in this area is not as developed as other topics related to attention. Developing an experimental protocol that requires participants to do almost nothing for long periods of time can be much more difficult than designing experiments to test boredom in monotonous task environments that typically last about 20 minutes. Participant recruitment, variation in participants' coping strategies, and measurable data to collect for analysis are just some of the difficulties encountered in investigating low task load studies as opposed to monotonous and repetitive experiments.

Subjective measures of boredom are often the most commonly ones used, but more recently physiological and implicit task-related measures are often used to assess boredom. This section will present these assessment methods as well as discuss the areas for future improvements.

Subjective Measurement

Due to the disagreement on the definition and underlying theory of boredom, there is no single or widely accepted scale for measuring boredom. Boredom measurement tools have been developed for specific contexts, each with its own advantages and limitations. An important distinction is between trait (a stable disposition) and state (a transient reaction) measures (Matthews, Davies, Westerman, & Stammers, 2000). For example, the general tendency to become bored is a trait, while the immediate experience of feeling bored is a state.

Some tools measure boredom as a trait. The most widely used scale in empirical research is Boredom Proneness Scale (BPS), which measures boredom as a trait (Farmer & Sundberg, 1986). It consists of 28 items (e.g., "It is easy for me to concentrate on my activities"; "Time always seems to be passing slowly"; "I am good at waiting patiently"). The original scale used true-false item format but was later transformed into 7-point Likert scale format. The reliability and factor structure of BPS has been investigated in several studies (Vodanovich, 2003). BPS has been used to investigate the relation between boredom and job satisfaction, vigilance reduction, aggressive driving, and many others (Dahlen et al., 2005; Kass, Vodanovich, & Callender, 2001; Sawin & Scerbo, 1995).

Others have proposed that boredom proneness should be viewed as a multidimensional construct, with external stimulation and internal stimulation as the two primary factors. The external stimulation factor reflects the low level of perceived environmental stimulation and the internal stimulation factor reflects the ability of people to entertain themselves(Vodanovich, Wallace, & Kass, 2005). External boredom proneness and internal boredom proneness are thought to have different impacts on behavior (Shaw et al., 2010). In one driving study, external boredom proneness was found to contribute to close calls or near misses, while internal boredom proneness predicted reduced adaptive driving anger expression (Dahlen et al., 2005).

Measurement of boredom as a trait often relates to personality scales. The widely used personality scales used to investigate boredom-related attributes are different versions of the NEO Personality Inventory and HEXACO. The NEO Personality Inventory measures the five factors of personality including Neuroticism, Extraversion, Openness to Experience, Agreeableness, and Conscientiousness (Costa & McCrae, 1992). HEXACO uses a six-dimensional structure containing Honesty-Humility, Emotionality, Extraversion, Agreeableness, Conscientiousness, and Openness to Experience (Ashton & Lee, 2007). It was found that external boredom proneness was negatively associated with Honesty/Humility, Emotionality, and Conscientiousness. Internal boredom proneness was related directly to Extraversion, Conscientiousness, and Openness to Experience (Culp, 2006).

There are a few other subjective measures of boredom as a trait. The Boredom Susceptibility Scale is a subscale of the Sensation Seeking Scale (Zuckerman, 1971). One study that compares the Boredom Proneness Scale and the Boredom Susceptibility Scale shows that they relate to different personality traits and behaviors (Mercer-Lynn, Flora, Fahlman, & Eastwood, 2013). Building on the Boredom Susceptibility Scale and other scales, Hamilton et al. (1984) developed the Boredom Coping scale, which focuses on how individuals restructure their perceptions and participation in potentially boring activities to cope with boredom.

State measures of boredom are generally less developed comparing to trait measures. A few other scales reviewed by Vodanovich (2003) attempt to measure the state of boredom including the Job Boredom, Leisure Boredom, Free Time Boredom, and Sexual Boredom scales. Although these scales measure boredom, they are used in different contexts or measure different constructs.

The Multidimensional State Boredom Scale (MSBS) was developed to measure boredom as a state instead of a trait, which includes five factors, namely Disengagement, High Arousal, Low Arousal, Inattention, and Time Perception (Fahlman, Mercer-Lynn, Flora, & Eastwood, 2013). State boredom can also be measured using the method of experience sampling in which participants are signaled on a random time schedule to write down information about their momentary situations and psychological states on a self-report questionnaire (Csikszentmihalyi & Larson, 1987). Participants can also be asked about how strongly they experienced boredom at a particular moment (Nett, Goetz, & Hall, 2011). Experience sampling has also been used to investigate TUTs (Smallwood, Nind, & O'Connor, 2009).

Another related yet different construct is workload. Boredom assesses both the external environment stimuli and internal personality traits, while workload measures are about an individual's ability to cope with the task requirements. Thus while subjective workload rating scales such as the NASA-TLX have been validated in a number of high workload studies (Hart, 2006), it is not clear whether such workload scales can accurately capture the influences of boredom. More importantly, although boredom often happens in low workload environments, it can also occur in high workload environment where the task is monotonous or repetitive (Warm, Parasuraman, et al., 2008).

Implicit Task-related Measures

Since boredom has an impact on task performance, it can also be indexed indirectly through task-related measures. One type of measure is based on attention. As suggested by the BID in Figure 1, low task engagement and distraction in a low task load environment can be indicative of boredom. For example, in a four-hour low task environment of one operator supervising four UAVs, participants spent almost half of the time in a distracted state overall suggesting they were bored (Cummings, Mastracchio, Thornburg, & Mkrtchyan, 2013). As the study progressed, this boredom came at a cost of increased reaction times to system prompts to replan and generate search tasks, as well as text messages asking for information.

Such results parallel similar results in vigilance studies, where reaction times, false alarms, and stimuli missed increase over time, and such changes in performance are likely an indicator for mental fatigue, which could be influenced by boredom (Azarnoosh, Nasrabadi, Mohammadi, & Firoozabadi, 2012; Ballard, 1996; Scerbo, 1998b). However, one problem with the use of implicit measures is their infrequency. By definition, boring work without monotonous tasking, like that seen in process control plants where operators monitor a plant for several hours without ever touching a control device, have little stimulation and thus few observable events. For manual driving and semi-automated driving, performance can be monitored based on steering behavior, speed control, and lane keeping. In highly automated driving, these variables no longer provide much information as the automation is in control (Merat, Jamson, Lai, & Carsten, 2012; Saxby et al., 2013). Thus, implicit measures in such systems are problematic. What is needed is some form of continuous feedback that can provide information about an operator's cognitive state, which will be discussed in the next section.

Physiological Measures

Physiological measures of boredom are different from subjective measures in several aspects. Physiological signals reflect state rather than trait boredom as measured by BPS. Although subjective scales for state boredom exist, physiological measures could provide for continuous monitoring of the human cognitive/emotional state, enabling adaptive intervention for boredom.

Physiological measures such as heart rate, heart rate variability, electrocardiogram (ECG), skin conductance, electroencephalogram (EEG), and functional Near Infrared Spectroscopy (fNIRS) have been used to measure the level of arousal and cognitive workload across a number of settings. However, far less work has been done on detecting and interpreting boredom given physiological signals. The limited understanding of the mechanism of boredom makes it difficult to measure. Moreover, boredom often occurs together with other states such as fatigue and frustration. Hill and Perkins (1985) concluded that changes in heart rate or heart rate variability are not consequences of boredom but task load. It is challenging to isolate the indicators of boredom, which can vary greatly across individuals, and distinguish it from other states.

For the limited studies that have attempted to measure boredom with physiological instruments, they sometimes produce conflicting results. In a study with varying difficulty levels for a tile-matching puzzle game, players in the easy level (which induced boredom) showed higher skin resistance, lower heart rate, and higher skin temperature than those in the medium and hard levels that produced increasing anxiety (Chanel, Rebetez, Bétrancourt, & Pun, 2008). This is partly consistent with an earlier study for air traffic controllers, where the high boredom group showed higher skin conductance, lower heart rate, lower blood pressure, and more body movement compared to the low boredom group (Thackray, Bailey, & Touchstone, 1977). By contrast, in a study comparing boredom, sadness, and interest introduced by viewing video clips, boredom showed rising heart rate, decreased skin conductance, and increased cortisol level relative to sadness (Merrifield & Danckert, 2014). In a study that examined alert maintenance during driving, heart rate variability decreased and the power of EEG alpha waves increased with alert maintaining tasks (Oron-Gilad et al., 2008).

Several studies have attempted to classify boredom with machine learning methods, with relative good accuracy. In one study where participants performed anagram-solving tasks while playing Pong, their emotional states were assessed using a self-report questionnaire and physiological signals were measured. Boredom with three intensity levels (high, medium, low) was then classified with an accuracy of 84.23% based on signals including electrocardiogram, bio-impedance, electromyogram (from the corrugator, zygomaticus, and upper trapezius muscles), electrodermal activity, peripheral temperature, blood volume pulse, and heart sound (Rani, Liu, Sarkar, & Vanman, 2006). In another study where participants played 3D video games, using moment-based features of ECG and Galvanic Skin Response, binary classification accuracy was improved 94.17% for the states of bored or not bored (Giakoumis, Tzovaras, Moustakas, & Hassapis, 2011).

Unfortunately because these studies are very specific to the test beds used, and contain low numbers of individual participants with different feature sets, it is difficult to compare the studies and draw definitive conclusions on how to use physiological signals to measure boredom.

Although not used for direct measure of boredom, neurophysiological signals have been used to assess workload and attention. When required to respond to rare and random events in a modified Mackworth Clock task (detecting a jump of the pointer in otherwise regular ticks), increased activity in the α-frequency range (8–14 Hz) of EEG was observed emerging and gradually accumulating 10s before a missed target. Daydreaming and TUTs have been measured via EEG power band ratios in the intervals immediately preceding and following a participant's report of a TUT (Cunningham et al., 2000).

In additional EEG research using a modified Mackworth Clock task, a significant gradual attenuation of the P3 event-related component was found to antecede stimuli misses by 5s (Martel, Dähne, & Blankertz, 2014). P3 (or P300) stands for a positive deflection in the event-related voltage potential at about 300-millisecond post stimulus. Its amplitude increases with unpredictable, unlikely, or highly significant stimuli and thereby constitutes an index of mental activity (Campbell, 2004).

fNIRs has been shown to capture workload changes in long duration low workload environments (Afergan et al., 2014; Boyer, 2014). fNIRs measurement during vigilance tasks has shown increased right hemisphere relative to left hemisphere oxygenation and right hemisphere oxygenation increased with time-on-task (De Joux, Russell, & Helton, 2013). Similarly, studies of transcranial cerebral blood flow velocity (CBFV) have also shown that the vigilance decrement is accompanied by a decline in global CBFV with a corresponding elevation of CBFV that occurs when a signal is detected (Shaw et al., 2013; Warm, Parasuraman, et al., 2008).

In a study comparing flow and boredom state, oxygen–hemoglobin concentration in the prefrontal cortex tended to decrease in the boredom condition (Yoshida et al., 2014). Although still in the early research stages, these studies show the potential to monitor and possibly one day even predict the change of operator status, which could then lead to potential real-time interventions.

While the use of psychophysiological signals to identify low periods of cognitive engagement, boredom, or distraction is still in its infancy, such research is important since these signals will be crucial in the development of models that can predict negative consequences as a result of long periods of inactivity and boredom. For example, in one study looking at military operators monitoring ballistic missile operations, participants who were frequent gamers, not distracted, scored low on the NEO FFI-3 Agreeableness rating scale, and showed an increase in deoxygenated hemoglobin, were more likely to perform better under a shift from very low to very high task loading (Boyer, 2014). Ideally, such models would eventually be able to be used in real time to flag operators in trouble.

V. Future Considerations

While the issues of boredom in the workplace in general, and more specifically in highly automated environments, are known to researchers and practitioners, they have generally not been as well researched as in other areas such as vigilance and the effect of high workload on performance. The intent of this review was to present a framework by which to organize the various facets of boredom, particularly in supervisory control settings, and to demonstrate the research gaps and future potential areas for study.

Because of the move towards more automated systems in the future, a better understanding is needed to enable intervention and mitigation of possible negative impacts. We propose that such mitigations can occur along two axes, that of selecting personnel that are less prone to boredom (endogenous sources of boredom) and improving system and task design (exogenous sources of boredom).

Individual Differences and Personnel Selection

While it will not be possible to preferentially select operators who are not prone to boredom in domains where automated technology is ubiquitous, such as driving, for other domains like nuclear power plant control and UAV operations, screening personnel is already part of the culture.

Individual variability can play a large role in both success and failure in managing low task load environments. People who are reportedly less prone to boredom have been shown to have better performance in vigilance tasks in terms of the frequency of signal detection as compared to people who score high on the boredom proneness scale (Sawin & Scerbo, 1995). In another study, boredom-prone medical and clinical laboratory technologists received lower performance rating from their supervisors (Watt & Hargis, 2010). Boredom proneness also correlates with boredom at work and impacts work satisfaction and absenteeism(Kass et al., 2001). Experience, age, intellectual capacity, gender, and personality type have all been suggested as contributors to individual variability of perceived boredom (Drory, 1982; Fisher, 1993; Harvey, Heslop, & Thorpe, 2010; Thackray et al., 1974; Vodanovich & Kass, 1990b).

The frequency of playing video games may provide additional insight as to what kind of person performs well in potentially boring environments. In one experiment looking at the degree of video gaming and performance in a boring low task load UAV control environment, frequent gamers performed worse that those who were not gamers (Cummings et al., 2013). These same gamers performed well under high workload conditions (Cummings, Clare, & Hart, 2010), which raises the question as to how personnel should be selected given potential exposure to both low and high task loads.

Such interactions of the environment with individual differences have not been studied to any depth. In one air traffic control task study, it has been suggested that task characteristics of repetitiveness and traffic density may interact with individual influence (e.g. personality, experience, age) in a way that causes monotony and boredom (Straussberger & Schaefer, 2007), but more work is needed in this area. Moreover, with distractions such as smart phones so readily available, the link between perceived boredom and distraction is another area that deserves more focus. Washburn et al. (2015) suggested that selection, training, and assignment of individuals in applied-perception contexts should be guided by individual differences in the capacity to maintain executive attention in the face of competing experiential and environmental constraints.

While it is unlikely that any variable could successfully predict performance alone, some attempts have been made to evaluate personal using a multivariate approach

(Matthews, Warm, Shaw, & Finomore, 2010, 2014). Results show that individual ability in reasoning and vocabulary, performance on short vigilance tasks, task engagement, task-focus coping, and avoidance coping explains 30% of the variance on vigilance performance of long durations. Clearly more objective quantitative data are needed in these areas to understand the interaction of the individual with tedious supervisory control environments, particularly in domains that could require time-pressured responses like those in military command and control environments, as well as process control settings.

System and Task Design

Given that automation is becoming more prevalent in complex and simple systems, more research is needed in mitigating negative consequences as a result of long periods of inactivity and boredom, for both experts who are highly trained and for widely varying populations such as those in driving domains. Based on the strategies people use to cope with boredom, the systems and tasks could be designed so that the environment is not as boring and potentially distraction-inducing.

One basic strategy is to schedule tasks so that human operators get enough breaks and rests to recover from boredom (Azizi, Zolfaghari, & Liang, 2010). In line with the boredom coping strategies, task design can be improved by including a secondary task that is stimulating, but not demanding. In one study, drivers that made fewer errors/misses during a monotonous laboratory task tended to experience larger variance in actual engine speed control with fewer accidents in their driving record. These drivers tended to introduce various task unrelated activities during monotonous driving such as looking for deer on the side of the road, which both reduced boredom and increased alertness (McBain, 1970). Another study demonstrated that an interactive cognitive task could combat fatigue in monotonous driving environments (Gershon, Ronen, Oron-Gilad, & Shinar, 2009).

Additional past research has shown that monitoring performance can be improved through dividing attention across tasks (Gould & Schaffer, 1967; Tyler & Halcomb, 1974). However, this research in a naturalistic setting demonstrated that operators were far less likely to divide their attention than to be completely distracted. Indeed, there is an increasing body of literature that shows that people are not as effective at dividing their attention as they might think (Loukopoulos, Dismukes, & Barshi, 2012; Ophir, Nass, & Wagner, 2009).

The third aspect of task design is to reconsider the level of automation. While increasing the level of automation is the goal of many system designers, they should also consider its impact when there are humans in the loop (Parasuraman, Sheridan, & Wickens, 2000). In a recent study on automated driving, responses to critical incidents involving an obstruction in the driver's lane were worse when distracted under automated driving conditions as compared to manual driving (Merat et al., 2012). From this perspective, decreasing the level of automation, at least partially, may be beneficial for system performance.

Two approaches that have been shown to improve performance and maintain situation awareness when monitoring automated systems are: 1) intermediate levels of automation to maintain engagement in complex system control, and 2) adaptive automation for managing operator workload through dynamic task allocation between the human and machine (Kaber & Endsley, 2004). In a study looking at automation monitoring during multitask flight simulations, performance on automation failure detection was better with adaptive task allocation that temporarily returned the control from the automation to a human operator than when under full automation control (Parasuraman, Mouloua, & Molloy, 1996). When implementing dynamic control allocation, issues such as the decision authority, triggers of control changes, and task characteristics must be carefully evaluated (Johnson, Oman, Sheridan, & Duda, 2014).

This review of boredom, its impact and coping strategies used the Boredom Influence Diagrams as a way to connect current insights in boredom research, and identify gaps that need further exploration. While the entire field could benefit from additional research, we feel that there are several areas that need specific attention. First, developing more naturalistic experiments that reflect the characteristics of a boring work environment are needed. This is very difficult to do in practice, but such experiments will likely lead to much richer data.

In addition, developing a continuous measurement of boredom based on physiological signals is also critical. Reliable physiological measures taken over time could potentially resolve disagreement among different theories and allow adaptive system design to cope with boredom. Lastly, more work is needed to look at mitigation interventions, both in terms of endogenous (i.e., personnel selection) and exogenous attributes (i.e., system and task design). Unfortunately, boredom mitigation is linked to boredom detection, so this highlights the need for more direct measures of boredom even more.

The presence of automation in the workplace is only going to increase, bringing a myriad of boredom-related problems. For example, the mining industry is quickly moving towards almost complete automation, where minerals are automatically extracted, and then transported via automated rail to shipping hubs (Kara, 2013). Driverless cars, while now in the experimental stage, are optimistically projected to be available to the general public by 2020 (Gannes, 2014). While the automated advances in these systems could increase safety and efficiency, these and other such supervisory control systems will require a human to at least be in the loop, and able to intervene when systems degrade or fail. However, these same systems will likely induce boredom when they reliably operate for long periods of time, and how to design the system, including appropriate function allocation, will be critical.

Key Points:

- With the increase in automation, boredom in the workplace will likely become a more prevalent issue for motivation and retention.
- Boredom can be represented in a systems framework that depicts the relationship between vigilance, individual differences, and task design.
- More work is needed to develop better experimental methods to measure boredom as well as mitigations to alleviate boredom.

References

Aaronson, L. S., Teel, C. S., Cassmeyer, V., Neuberger, G. B., Pallikkathayil, L., Pierce, J., . . . Wingate, A. (1999). Defining and measuring fatigue. *Image: the Journal of Nursing Scholarship, 31*, 45-50.

Abramson, E. E., & Stinson, S. G. (1977). Boredom and eating in obese and non-obese individuals. *Addictive Behaviors, 2*, 181-185.

Afergan, D., Peck, E. M., Solovey, E. T., Jenkins, A., Hincks, S. W., Brown, E. T., . . . Jacob, R. J. K. (2014). *Dynamic difficulty using brain metrics of workload*. Paper presented at the Proceedings of the 32nd annual ACM conference on Human factors in computing systems, Toronto, Ontario, Canada.

Ahmed, S. (1990). Psychometric properties of the boredom proneness scale. *Perceptual and Motor Skills, 71*, 963-966.

Alves, E. E., & Kelsey, C. M. (2010). Combating vigilance decrement in a single-operator radar platform. *Ergonomics in Design: The Quarterly of Human Factors Applications, 18*, 6-9.

Ashton, M. C., & Lee, K. (2007). Empirical, theoretical, and practical advantages of the hexaco model of personality structure. *Personality and Social Psychology Review, 11*, 150-166.

Atchley, P., & Chan, M. (2011). Potential benefits and costs of concurrent task engagement to maintain vigilance: A driving simulator investigation. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 53*, 3-12.

Azarnoosh, M., Nasrabadi, A. M., Mohammadi, M. R., & Firoozabadi, M. (2012). Evaluating nonlinear variability of mental fatigue behavioral indices during long-term attentive task. *Complexity, 17*, 7-16.

Azizi, N., Zolfaghari, S., & Liang, M. (2010). Modeling job rotation in manufacturing systems: The study of employee's boredom and skill variations. *International Journal of Production Economics, 123*, 69-85.

Bainbridge, L. (1983). Ironies of automation. *Automatica, 19*, 775-779.

Ballard, J. C. (1996). Computerized assessment of sustained attention: A review of factors affecting vigilance performance. *Journal of Clinical and Experimental Neuropsychology, 18*, 843-863.

Barata, G., Gama, S., Jorge, J., & Goncalves, D. (2013, September). *Engaging engineering students with gamification.* Paper presented at the Games and Virtual Worlds for Serious Applications (VS-GAMES), 2013 5th International Conference on (pp. 1-8). IEEE

Barmack, J. E. (1937). *Boredom and other factors in the physiology of mental effort: An exploratory study*. New York: Columbia university.

Barmack, J. E. (1939). Studies on the psychophysiology of boredom: Part I. The effect of 15 mgs. of benzedrine sulfate and 60 mgs. of ephedrine hydrochloride on blood pressure, report of boredom and other factors. *Journal of Experimental Psychology, 25*, 494-505.

Becker, A. B., Warm, J. S., Dember, W. N., & Hancock, P. A. (1991). Effects of feedback on perceived workload in vigilance performance. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 35*, 1491-1494.

Boksem, M. A. S., Meijman, T. F., & Lorist, M. M. (2005). Effects of mental fatigue on attention: An ERP study. *Cognitive Brain Research, 25*, 107-116.

Boyer, M. W. (2014). *The impact of rapid transitions in mental workload in a supervisory control setting.* Massachusetts Institute of Technology.

Britton, A., & Shipley, M. J. (2010). Bored to death? *International Journal of Epidemiology, 39*, 370-371.

Bruursema, K., Kessler, S. R., & Spector, P. E. (2011). Bored employees misbehaving: The relationship between boredom and counterproductive work behaviour. *Work & Stress, 25*, 93-107.

Campbell, R. J. (2004). *Campbell's psychiatric dictionary*. New York: Oxford University Press.

Carpenito-Moyet, L. J. (2006). *Nursing diagnosis: Application to clinical practice*. Philadelphia: Lippincott Williams & Wilkins.

Casner, S. M., & Schooler, J. W. (2014). Thoughts in flight: Automation use and pilots' task-related and task-unrelated thought. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 56*, 433-442.

Casner, S. M., & Schooler, J. W. (2015). Vigilance impossible: Diligence, distraction, and daydreaming all lead to failures in a practical monitoring task. *Consciousness and Cognition, 35*, 33-41.

Chanel, G., Rebetez, C., Bétrancourt, M., & Pun, T. (2008, October). *Boredom, engagement and anxiety as indicators for adaptation to difficulty in games.* Paper presented at the Proceedings of the 12th international conference on Entertainment and media in the ubiquitous era (pp. 13-17), Tampere, Finland. ACM

Chappelle, W., McDonald, K., Prince, L., Goodman, T., Ray-Sannerud, B. N., & Thompson, W. (2014). Assessment of occupational burnout in United States Air Force Predator/Reaper “drone” operators. *Military Psychology, 26*, 376-385.

Christoff, K., Ream, J. M., & Gabrieli, J. D. E. (2004). Neural basis of spontaneous thought processes. *Cortex, 40*, 623-630.

Costa, P. T., & McCrae, R. R. (1992). Normal personality assessment in clinical practice: The NEO Personality Inventory. *Psychological Assessment, 4*, 5-13.

Csikszentmihalyi, M. (1978). Attention and the holistic approach to behavior. In K. Pope & J. Singer (Eds.), *The Stream of Consciousness* (pp. 335-358). New York, NY: Plenum.

Csikszentmihalyi, M. (2014). Toward a psychology of optimal experience. In *Flow and the foundations of positive psychology* (pp. 209-226). Netherlands: Springer Netherlands.

Csikszentmihalyi, M., & Larson, R. (1987). Validity and reliability of the experience-sampling method. *The Journal of nervous and mental disease, 175*, 526-536.

Culp, N. A. (2006). The relations of two facets of boredom proneness with the major dimensions of personality. *Personality and Individual Differences, 41*, 999-1007.

Cummings, M. (2008). Of shadows and white scarves. *C4ISR Journal, 7*, 17-18.

Cummings, M. L., Clare, A., & Hart, C. (2010). The role of human-automation consensus in multiple unmanned vehicle scheduling. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 52*, 17-27.

Cummings, M. L., How, J. P., Whitten, A., & Toupet, O. (2012). The impact of human-automation collaboration in decentralized multiple unmanned vehicle control. *Proceedings of the IEEE, 100*, 660-671.

Cummings, M. L., Mastracchio, C., Thornburg, K. M., & Mkrtchyan, A. (2013). Boredom and distraction in multiple unmanned vehicle supervisory control. *Interacting with Computers, 25*, 34-47.

Cunningham, S., Scerbo, M. W., & Freeman, F. G. (2000). The electrocortical correlates of daydreaming during vigilance tasks. *Journal of Mental Imagery, 24*, 61-72.

Dahlen, E. R., Martin, R. C., Ragan, K., & Kuhlman, M. M. (2005). Driving anger, sensation seeking, impulsiveness, and boredom proneness in the prediction of unsafe driving. *Accident Analysis & Prevention, 37*, 341-348.

Daniels, L. M., Tze, V. M. C., & Goetz, T. (2015). Examining boredom: Different causes for different coping profiles. *Learning and Individual Differences, 37*, 255-261.

Davies, D. R., & Parasuraman, R. (1982). *The psychology of vigilance*. London: Academic Press.

De Joux, N., Russell, P. N., & Helton, W. S. (2013). A functional near-infrared spectroscopy study of sustained attention to local and global target features. *Brain and Cognition, 81*, 370-375.

Desmond, P. A., & Hancock, P. A. (2001). Active and passive fatigue states. In P. A. Hancock & P. A. Desmond (Eds.), *Stress, workload and fatigue* (pp. 455-465). Mahwah, NJ: Lawrence Erlbaum Associates.

Dittmar, M. L., Warm, J. S., Dember, W. N., & Ricks, D. F. (1993). Sex differences in vigilance performance andperceived workload. *The Journal of General Psychology, 120*, 309-322.

Drory, A. (1982). Individual differences in boredom proneness and task effectiveness at work. *Personnel Psychology, 35*, 141-151.

Dunn, N., & Williamson, A. (2011, July). *Monotony in the rail industry: The role of task demand in mitigating monotony-related effects on performance.* Paper presented at the Ergonomics Australia–HFESA 2011 Conference Edition.

Eastwood, J. D., Frischen, A., Fenske, M. J., & Smilek, D. (2012). The unengaged mind: Defining boredom in terms of attention. *Perspectives on Psychological Science, 7*, 482-495.

Fahlman, S. A., Mercer-Lynn, K. B., Flora, D. B., & Eastwood, J. D. (2013). Development and validation of the multidimensional state boredom scale. *Assessment, 20*, 68-85.

Farmer, R., & Sundberg, N. D. (1986). Boredom proneness--the development and correlates of a new scale. *Journal of Personality Assessment, 50*, 4-17.

Fenichel, O. (1951). On the psychology of boredom. In D. Rapaport (Ed.) *Organization and pathology of thought: Selected sources* (pp. 349-361). New York, NY: Columbia University Press.

Finomore, V. S., Shaw, T. H., Warm, J. S., Matthews, G., & Boles, D. B. (2013). Viewing the workload of vigilance through the lenses of the NASA-TLX and the MRQ. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 55*, 1044-1063.
Fisher, C. D. (1993). Boredom at work: A neglected concept. *Human Relations, 46*, 395-417.
Fisher, C. D. (1998). Effects of external and internal interruptions on boredom at work: two studies. *Journal of Organizational Behavior, 19*, 503-522.
Frederick-Recascino, C. M., & Hilscher, M. (2001, October). *Monitoring automated displays: Effects of and solutions for boredom.* Paper presented at the Digital Avionics Systems, 2001. DASC. 20th Conference.
Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention, 37*, 461-472.
Gannes, L. (2014, May 13). Here's what it's like to go for a ride in google's robot car. Retrieved from http://recode.net/2014/05/13/googles-self-driving-car-a-smooth-test-ride-but-a-long-road-ahead/
Gershon, P., Ronen, A., Oron-Gilad, T., & Shinar, D. (2009). The effects of an interactive cognitive task (ICT) in suppressing fatigue symptoms in driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 12*, 21-28.
Giakoumis, D., Tzovaras, D., Moustakas, K., & Hassapis, G. (2011). Automatic recognition of boredom in video games using novel biosignal moment-based features. *Affective Computing, IEEE Transactions on, 2*, 119-133.
Gould, J. D., & Schaffer, A. M. Y. (1967). Eye-movement parameters in pattern recognition. *Journal of Experimental Psychology, 74*, 225-229.
Grier, R. A., Warm, J. S., Dember, W. N., Matthews, G., Galinsky, T. L., Szalma, J. L., & Parasuraman, R. (2003). The vigilance decrement reflects limitations in effortful attention, not mindlessness. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 45*, 349-359.
Haga, S. (1984). An experimental study of signal vigilance errors in train driving. *Ergonomics, 27*, 755-765.
Hamilton, J. A., Haier, R. J., & Buchsbaum, M. S. (1984). Intrinsic enjoyment and boredom coping scales: Validation with personality, evoked potential and attention measures. *Personality and Individual Differences, 5*, 183-193.
Hamilton-Baillie, B. (2008). Shared space: Reconciling people, places and traffic. *Built Environment, 34*, 161-181.
Harris, M. B. (2000). Correlates and characteristics of boredom proneness and boredom. *Journal of Applied Social Psychology, 30*, 576-598.
Hart, S. G. (2006). Nasa-Task Load Index (NASA-TLX); 20 years later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 50*, 904-908.
Harvey, J., Heslop, S., & Thorpe, N. (2010). The categorisation of drivers in relation to boredom. *Transportation Planning and Technology, 34*, 51-69.
Heslop, S., Harvey, J., Thorpe, N., & Mulley, C. (2009). Factors that comprise driver boredom and their relationships to preferred driving speed and demographic variables. *Transportation Planning and Technology, 33*, 75-89.
Hill, A. B., & Perkins, R. E. (1985). Toward a model of boredom. *British Journal of Psychology, 76*, 235-240.
Hitchcock, E. M., Dember, W. N., Warm, J. S., Moroney, B. W., & See, J. E. (1999). Effects of cueing and knowledge of results on workload and boredom in sustained attention. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 41*, 365-372.
Hockey, G. R. J. (1997). Compensatory control in the regulation of human performance under stress and high workload: A cognitive-energetical framework. *Biological Psychology, 45*, 73-93.
John, M., Smallman, H. S., & Manes, D. I. (2005). Recovery from Interruptions to a Dynamic Monitoring Task: The Beguiling Utility of Instant Replay. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 49*, 473-477.
Johnson, A. W., Oman, C. M., Sheridan, T. B., & Duda, K. R. (2014, March). *Dynamic task allocation in operational systems: Issues, gaps, and recommendations.* Paper presented at the Aerospace Conference, 2014 (pp. 1-15). IEEE
Kaber, D. B., & Endsley, M. R. (2004). The effects of level of automation and adaptive automation on human performance, situation awareness and workload in a dynamic control task. *Theoretical Issues in Ergonomics Science, 5*, 113-153.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall.
Kara, D. (2013, October 9). Rio tinto rolls out ambitious, autonomous, mine of the future. Retrieved from http://www.arisplex.com/analysis/rio-tinto-rolls-ambitious-autonomous-mine-future/
Kass, S., Vodanovich, S., & Callender, A. (2001). State-trait boredom: Relationship to absenteeism, tenure, and job satisfaction. *Journal of Business and Psychology, 16*, 317-327.
Kass, S. J., & Vodanovich, S. J. (1990). Boredom proneness: Its relationship to Type A behavior pattern and sensation seeking. *Psychology: A Journal of Human Behavior, 27*, 7-16.
Killingsworth, M. A., & Gilbert, D. T. (2010). A wandering mind is an unhappy mind. *Science, 330*, 932-932.
Krueger, G. P. (1989). Sustained work, fatigue, sleep loss and performance: A review of the issues. *Work & Stress, 3*, 129-141.
Lal, S. K. L., & Craig, A. (2001). A critical review of the psychophysiology of driver fatigue. *Biological Psychology, 55*, 173-194.
Lee, K. A., Hicks, G., & Nino-Murcia, G. (1991). Validity and reliability of a scale to assess fatigue. *Psychiatry Research, 36*, 291-298.
LePera, N. (2011). The relationships between boredom proneness, mindfulness, anxiety, depression, and substance use. *The New School Psychology Bulletin, 8*(2), 15-25.
Locke, E. A., & Bryan, J. F. (1967). Performance goals as determinants of level of performance and boredom. *Journal of Applied Psychology, 51*, 120-130.
Loh, S., Lamond, N., Dorrian, J., Roach, G., & Dawson, D. (2004). The validity of psychomotor vigilance tasks of less than 10-minute duration. *Behavior Research Methods, Instruments, & Computers, 36*, 339-346.
Loukidou, L., Loan-Clarke, J., & Daniels, K. (2009). Boredom in the workplace: More than monotonous tasks. *International Journal of Management Reviews, 11*, 381-405.
Loukopoulos, L. D., Dismukes, R. K., & Barshi, I. (2012). *The multitasking myth: Handling complexity in real-world operations*. Farnham, UK: Ashgate Publishing, Ltd.
Mackworth, N. H. (1957). Some factors affecting vigilance. *Advancement of Science, 53*, 389-393.
Malkovsky, E., Merrifield, C., Goldberg, Y., & Danckert, J. (2012). Exploring the relationship between boredom and sustained attention. *Experimental Brain Research, 221*, 59-67.
Martel, A., Dähne, S., & Blankertz, B. (2014). EEG predictors of covert vigilant attention. *Journal of Neural Engineering, 11*, 035009.
Matthews, G., & Campbell, S. E. (1998). Task-induced stress and individual differences in coping. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 42*, 821-825.
Matthews, G., Davies, D. R., Westerman, S. J., & Stammers, R. B. (2000). *Human performance: Cognition, stress, and individual differences*. East Sussex, UK: Psychology Press.
Matthews, G., Hancock, P. A., Desmond, P. A., & Neubauer, C. (2012). *The handbook of operator fatigue*. Burlington, VT: Ashgate Publishing Company.
Matthews, G., Warm, J. S., Reinerman-Jones, L. E., Langheim, L. K., Washburn, D. A., & Tripp, L. (2010). Task engagement, cerebral blood flow velocity, and diagnostic monitoring for sustained attention. *Journal of Experimental Psychology: Applied, 16*, 187-203.
Matthews, G., Warm, J. S., Shaw, T. H., & Finomore, V. S. (2010). A multivariate test battery for predicting vigilance. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 54*, 1072-1076.
Matthews, G., Warm, J. S., Shaw, T. H., & Finomore, V. S. (2014). Predicting battlefield vigilance: a multivariate approach to assessment of attentional resources. *Ergonomics, 57*, 856-875.
McBain, W. N. (1970). Arousal, monotony, and accidents in line driving. *Journal of Applied Psychology, 54*, 509-519.
McDowall, R. J. S., & Wells, H. M. (1927). The physiology of monotony. *British Medical Journal, 1*, 414-415.
McIntosh, J., MacDonald, F., & McKeganey, N. (2005). Pre-teenage children's experiences of drug use. *International Journal of Drug Policy, 16*, 37-45.
McVay, J. C., & Kane, M. J. (2010). Does mind wandering reflect executive function or executive failure? Comment on Smallwood and Schooler (2006) and Watkins (2008). *Psychological Bulletin, 136*, 188-197.

Merat, N., Jamson, A. H., Lai, F. C. H., & Carsten, O. (2012). Highly automated driving, secondary task performance, and driver state. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 54*, 762-771.

Mercer-Lynn, K. B., Flora, D. B., Fahlman, S. A., & Eastwood, J. D. (2013). The measurement of boredom: Differences between existing self-report scales. *Assessment, 20*, 585-596.

Merrifield, C., & Danckert, J. (2014). Characterizing the psychophysiological signature of boredom. *Experimental Brain Research, 232*, 481-491.

Mikulas, W. L., & Vodanovich, S. J. (1993). The essence of boredom. *The Psychological Record, 43*, 3-12.

Mkrtchyan, A. A., Macbeth, J. C., Solovey, E. T., Ryan, J. C., & Cummings, M. L. (2012). Using variable-rate alerting to counter boredom in human supervisory control. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 56*, 1441-1445.

Morcom, A. M., & Fletcher, P. C. (2007). Does the brain have a baseline? Why we should be resisting a rest. *Neuroimage, 37*, 1073-1082.

Movie-watching air traffic controller suspended. (2011, April 19). Retrieved from http://www.cbsnews.com/stories/2011/04/18/national/main20055158.shtml

Nett, U. E., Goetz, T., & Hall, N. C. (2011). Coping with boredom in school: An experience sampling perspective. *Contemporary Educational Psychology, 36*, 49-59.

Nietzsche, F. (1878). *Human, all too human: A book for free spirits*.

Norman, D. A. (2004). *Emotional design: Why we love (or hate) everyday things*. Basic books.

Northwest Airlines Flight 188. (2009, November 25). Retrieved from http://www.faa.gov/data_research/accident_incident/2009-10-23/

O'Hanlon, J. F. (1981). Boredom: Practical consequences and a theory. *Acta Psychologica, 49*, 53-82.

Ophir, E., Nass, C., & Wagner, A. D. (2009). Cognitive control in media multitaskers. *Proceedings of the National Academy of Sciences, 106*, 15583-15587.

Oron-Gilad, T., Ronen, A., & Shinar, D. (2008). Alertness maintaining tasks (AMTs) while driving. *Accident Analysis & Prevention, 40*, 851-860.

Oron-Gilad, T., & Shinar, D. (2000). Driver fatigue among military truck drivers. *Transportation Research Part F: Traffic Psychology and Behaviour, 3*, 195-209.

Parasuraman, R. (1986). Vigilance, monitoring, and search. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performance, Vol. 2: Cognitive processes and performance* (pp. 1-39). Oxford, England: John Wiley & Sons.

Parasuraman, R., & Davies, D. R. (1977). A taxonomic analysis of vigilance performance. In R. R. Mackie (Ed.) *Vigilance: Theory, Operational Performance, and Physiological Correlates.* (Vol. 3, pp. 559-574). New York, NY: Plenum.

Parasuraman, R., & Manzey, D. H. (2010). Complacency and bias in human use of automation: An attentional integration. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 52*, 381-410.

Parasuraman, R., Mouloua, M., & Molloy, R. (1996). Effects of adaptive task allocation on monitoring of automated systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 38*, 665-679.

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans, 30*, 286-297.

Patten, C. J. D., Kircher, A., Östlund, J., & Nilsson, L. (2004). Using mobile telephones: cognitive workload and attention resource allocation. *Accident Analysis & Prevention, 36*, 341-350.

Pattyn, N., Neyt, X., Henderickx, D., & Soetens, E. (2008). Psychophysiological investigation of vigilance decrement: Boredom or cognitive fatigue? *Physiology & Behavior, 93*, 369-378.

Pop, V. L., Stearman, E. J., Kazi, S., & Durso, F. T. (2012). Using engagement to negate vigilance decrements in the NextGen environment. *International Journal of Human-Computer Interaction, 28*, 99-106.

Prinzel, L. J., & Freeman, F. G. (1997). Task-specific sex differences in vigilance performance: Subjective workload and boredom. *Perceptual and Motor Skills, 85*, 1195-1202.

Rani, P., Liu, C., Sarkar, N., & Vanman, E. (2006). An empirical study of machine learning techniques for affect recognition in human–robot interaction. *Pattern Analysis and Applications, 9*, 58-69.

Reinerman-Jones, L. E., Matthews, G., Langheim, L. K., & Warm, J. S. (2010). Selection for vigilance assignments: a review and proposed new direction. *Theoretical Issues in Ergonomics Science, 12*, 273-296.

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology, 39*, 1161-1178.

Sawin, D. A., & Scerbo, M. W. (1994). Vigilance: How to do it and who should do it. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 38*, 1312-1316.

Sawin, D. A., & Scerbo, M. W. (1995). Effects of instruction type and boredom proneness in vigilance: Implications for boredom and workload. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 37*, 752-765.

Saxby, D. J., Matthews, G., Warm, J. S., Hitchcock, E. M., & Neubauer, C. (2013). Active and passive fatigue in simulated driving: Discriminating styles of workload regulation and their safety impacts. *Journal of Experimental Psychology: Applied, 19*, 287-300.

Scerbo, M. W. (1998a). Sources of stress and boredom in vigilance. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 42*, 764-768.

Scerbo, M. W. (1998b). What's so boring about vigilance? In R. R. Hoffman, M. F. Sherrick, & J. S. Warm (Eds.), *Viewing psychology as a whole: The integrative science of William N. Dember* (pp. 145-166). Washington, DC: American Psychological Association.

Scerbo, M. W., Greenwald, C. Q., & Sawin, D. A. (1993). The effects of subject-controlled pacing and task type on sustained attention and subjective workload. *The Journal of General Psychology, 120*, 293-307.

Schroeder, D. J., Touchstone, R. M., Stern, J. A., Stoliarov, N., & Thackray, R. I. (1994). Maintaining vigilance on a simulated ATC monitoring task across repeated sessions (No. DOT/FAA/AM-94/6).

Schroeter, R., Oxtoby, J., & Johnson, D. (2014, September). *AR and gamification concepts to reduce driver boredom and risk taking behaviours.* Paper presented at the Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 1-8), Seattle, WA, USA. ACM

Scott, S. D., Mercier, S., Cummings, M. L., & Wang, E. (2006). Assisting Interruption Recovery in Supervisory Control of Multiple UAVs. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 50*, 699-703.

Shaw, T. H., Funke, M. E., Dillard, M., Funke, G. J., Warm, J. S., & Parasuraman, R. (2013). Event-related cerebral hemodynamics reveal target-specific resource allocation for both "go" and "no-go" response-based vigilance tasks. *Brain and Cognition, 82*, 265-273.

Shaw, T. H., Matthews, G., Warm, J. S., Finomore, V. S., Silverman, L., & Costa, P. T. (2010). Individual differences in vigilance: Personality, ability and states of stress. *Journal of Research in Personality, 44*, 297-308.

Sheridan, T. B., Vámos, T., & Aida, S. (1983). Adapting automation to man, culture and society. *Automatica, 19*, 605-612.

Smallwood, J., Davies, J. B., Heim, D., Finnigan, F., Sudberry, M., O'Connor, R., & Obonsawin, M. (2004). Subjective experience and the attentional lapse: Task engagement and disengagement during sustained attention. *Consciousness and Cognition, 13*, 657-690.

Smallwood, J., Nind, L., & O'Connor, R. C. (2009). When is your head at? An exploration of the factors associated with the temporal focus of the wandering mind. *Consciousness and Cognition, 18*, 118-125.

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin, 132*, 946-958.

Smith, R. P. (1981). Boredom: A review. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 23*, 329-340.

Sommers, J., & Vodanovich, S. J. (2000). Boredom proneness: Its relationship to psychological-and physical-health symptoms. *Journal of clinical psychology, 56*, 149-155.

Stager, P., Hameluck, D., & Jubis, R. (1989, October). *Underlying factors in air traffic control incidents.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting (pp. 43-46), Denver, Colorado. SAGE Publications

Straussberger, S., & Schaefer, D. (2007). Monotony in air traffic control. *Air traffic control quarterly, 15*, 183-207.

Sundberg, N. D., Latkin, C. A., Farmer, R. F., & Saoud, J. (1991). Boredom in young adults: Gender and cultural comparisons. *Journal of Cross-Cultural Psychology, 22*, 209-223.

Szalma, J. L., & Matthews, G. (2015). Motivation and Emotion in Sustained Attention. In R. R. Hoffman, P. A. Hancock, M. W. Scerbo, R. Parasuraman, & J. L. Szalma (Eds.), *The Cambridge Handbook of Applied Perception Research* (Vol. 1, pp. 218-240). New York, NY: Cambridge University Press.

Teaching 'the least boring job'. (2006, July 27). Retrieved from http://news.bbc.co.uk/2/hi/uk_news/education/5217736.stm

Thackray, R., Bailey, J. P., & Touchstone, R. M. (1977). Physiological, subjective, and performance correlates of reported boredom and monotony while performing a simulated radar control task. In R. R. Mackie (Ed.) *Vigilance: Theory, Operational Performance, and Physiological Correlates.* (Vol. 3, pp. 203-215). New York, NY: Plenum.

Thackray, R. I. (1981). The stress of boredom and monotony: A consideration of the evidence. *Psychosomatic Medicine, 43*, 165-176.

Thackray, R. I., Jones, K. N., & Touchstone, R. M. (1974). Personality and physiological correlates of performance decrement on a monotonous task requiring sustained attention. *British Journal of Psychology, 65*, 351-358.

Thiffault, P., & Bergeron, J. (2003). Monotony of road environment and driver fatigue: a simulator study. *Accident Analysis & Prevention, 35*, 381-391.

Thompson, W. T., Lopez, N., Hickey, P., DaLuz, C., Caldwell, J. L., & Tvaryanas, A. P. (2006). Effects of shift work and sustained operations: Operator performance in remotely piloted aircraft (OP-REPAIR) (No. HSW-PE-BR-TR-2006-0001).

Thomson, D. R., Besner, D., & Smilek, D. (2015). A resource-control account of sustained attention: Evidence from mind-wandering and vigilance paradigms. *Perspectives on Psychological Science, 10*, 82-96.

Thornburg, K. M., Peterse, H. P. M., Liu, A. M., & Oman, C. (2011). Operator performace in long duration, low task load control operations. Massachusetts Institute of Technology Humans and Automation Laboratory (HAL2011-04), Cambridge MA.

Tyler, D. M., & Halcomb, C. G. (1974). Monitoring Performance with a time-shared encoding task. *Perceptual and Motor Skills, 38*, 383-386.

Van Dongen, H. P. A., & Belenky, G. (2009). Individual differences in vulnerability to sleep loss in the work environment. *Industrial Health, 47*, 518-526.

Vodanovich, S. J. (2003). Psychometric measures of boredom: A review of the literature. *The Journal of Psychology, 137*, 569-595.

Vodanovich, S. J., & Kass, S. J. (1990a). Age and gender differences in boredom proneness. *Journal of Social Behavior and Personality, 5*, 297-307.

Vodanovich, S. J., & Kass, S. J. (1990b). A factor analytic study of the boredom proneness scale. *Journal of Personality Assessment, 55*, 115-123.

Vodanovich, S. J., Verner, K. M., & Gilbride, T. V. (1991). Boredom proneness: Its relationship to positive and negative affect. *Psychological Reports, 69*, 1139-1146.

Vodanovich, S. J., Wallace, J. C., & Kass, S. J. (2005). A confirmatory approach to the factor structure of the boredom proneness scale: Evidence for a two-factor short form. *Journal of Personality Assessment, 85*, 295-303.

Warm, J. S., Dember, W. N., & Hancock, P. A. (1996). Vigilance and workload in automated systems. In R. Parasuraman & M. Mouloua (Eds.), *Automation and human performance: Theory and applications* (pp. 183-200). Hillsdale, NJ: Lawrence Erlbaum Associates.

Warm, J. S., Finomore, V. S., Vidulich, M. A., & Funke, M. E. (2015). Vigilance: A perceptual challenge. In R. R. Hoffman, P. A. Hancock, M. W. Scerbo, R. Parasuraman, & J. L. Szalma (Eds.), *The Cambridge Handbook of Applied Perception Research* (Vol. 1, pp. 241-283). New York, NY: Cambridge University Press.

Warm, J. S., Matthews, G., & Finomore, V. S., Jr. (2008). Vigilance, workload, and stress. In P. A. Hancock & J. L. Szalma (Eds.), *Performance under stress* (pp. 115-141). Burlington, VT: Ashgate.

Warm, J. S., Parasuraman, R., & Matthews, G. (2008). Vigilance requires hard mental work and is stressful. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 50*, 433-441.

Washburn, D. A., Latzman, R. D., Schwartz, N. B., & Bramlett, J. (2015). Attention as a Cause and an Effect of Perception. In R. R. Hoffman, P. A. Hancock, M. W. Scerbo, R. Parasuraman, & J. L. Szalma (Eds.), *The Cambridge Handbook of Applied Perception Research* (Vol. 1, pp. 126-147). New York, NY: Cambridge University Press.
Watt, J., & Hargis, M. (2010). Boredom proneness: Its relationship with subjective underemployment, perceived organizational support, and job performance. *Journal of Business and Psychology, 25*, 163-174.
Weinger, M. (1999). Vigilance, boredom, and sleepiness. *Journal of Clinical Monitoring and Computing, 15*, 549-552.
Weinger, M., & Englund, C. (1990). Ergonomic and human factors affecting anesthetic vigilance and monitoring performance in the operating room environment. *Anesthesiology, 73*, 995-1021.
Wickens, C. D., Lee, J. D., Liu, Y., & Gordon-Becker, S. E. (2011). *An introduction to human factors engineering* (2 ed.). Upper Saddle River, NJ: Prentice Hall.
Wiener, E. L., & Nagel, D. C. (1988). *Human factors in aviation*. San Diego, CA: Academic Press.
Wiggins, M. W. (2011). Vigilance decrement during a simulated general aviation flight. *Applied Cognitive Psychology, 25*, 229-235.
Wilson, T. D., Reinhard, D. A., Westgate, E. C., Gilbert, D. T., Ellerbeck, N., Hahn, C., . . . Shaked, A. (2014). Just think: The challenges of the disengaged mind. *Science, 345*, 75-77.
Yoshida, K., Sawamura, D., Inagaki, Y., Ogawa, K., Ikoma, K., & Sakai, S. (2014). Brain activity during the flow experience: A functional near-infrared spectroscopy study. *Neuroscience Letters, 573*, 30-34.
Zuckerman, M. (1971). Dimensions of sensation seeking. *Journal of Consulting and Clinical Psychology, 36*, 45-52.

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