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Workload Transitions and Stress: Changes Over Time

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ABSTRACT

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Workload transitions are situations where operators are suddenly confronted with levels of workload substantially different from previously established levels. Workload transitions may affect the operators' state of stress and coping behaviors but previous research has not conclusively demonstrated the nature of those. The first goal of the current work was to investigate the discrepant findings of the previous literature. Two experiments were conducted where participants were asked to perform a digit detection task that suddenly shifted between low and high event rates (i.e., low and high workload, respectively). The first experiment used a large magnitude transition that resulted in a decrease in reported levels of task engagement and effort. Over time, the reported stress and workload ratings of the transitioned groups approached the nontransitioned control groups. A second experiment was conducted using a moderate magnitude transition. This second experiment replicated the findings from the first experiment, with the key difference being that the transition from a low to more a more moderate level of workload resulted in higher, sustained task engagement and effort. Two main conclusions are drawn from these results. First, over time the stress and workload levels of individuals who experience a transition will approach those reported by nontransitioned individuals. Future workload transition research must therefore consider the effect of the time from transition. Second, the magnitude of the transition may influence the coping response

such that a moderate transition may result in increased task-oriented, effortful coping whereas a large magnitude transition may result in decreased effortful coping.

This dissertation is dedicated to the memory of my father, Thomas Gunnar Prytz.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The purpose of this work was to investigate the relationship between workload transitions and stress. A workload transition occurs when operators have been working at an established level of task demand for a period of time and are then confronted with a substantially different level of task demand. The operators must respond to the new task demands rapidly and effectively but some research indicates that the transition may impact both performance and stress, regardless of whether the new task demands are greater or less than previous levels.

There are two main reasons why the issue of stress induced by workload transitions is important. First, workload transitions are common in many occupational situations where long monotonous periods are followed by intense, high-pressure periods, or vice versa. One prototypical example is the armed forces, where transitions from extreme underload (e.g., waiting or resting) to extreme overload (e.g., life-or-death combat) are common and famously stated as "hours of boredom punctuated by moments of sheer terror" (Hancock & Kreuger, 2010). In fact, the 1993 call for research on workload transitions by the National Research Council (Huey & Wickens, 1993) focused specifically on tank crews transitioning from waiting to combat.

Second, the relationship between workload transitions and stress is poorly understood. Less than two dozen studies have been published about workload transitions in general since the problem was first highlighted in 1968. Within these, only five studies have directly investigated stress. Thus, even though workload transitions are thought to be linked to stress (Huey & Wickens, 1993) and stress is an important factor, the relationship between the two has received little attention. To further complicate matters, the five studies that focused on stress arrived at conflicting results. Helton and his colleagues (Helton, Shaw, Warm, Matthews, Dember, & Hancock 2004; Helton, Saw, Warm, Matthews, & Hancock, 2008) and Morgan and Hancock (2011) found subjective stress to be elevated following a transition, Ungar (2008) found stress equal to non-shifted controls, and Hauck et al. (2008) found a decline in stress. Thus, the first goal of the current work was to answer the question: what factor or factors underlie these discrepant results?

CHAPTER II

BACKGROUND

WORKLOAD

"The deterioration in human performance resulting from adverse working conditions has naturally been one of the most widely studied of all psychological problems." N. Mackworth (1948), p. 6.

History of workload research. Workload is defined here as "the cognitive load associated with the mental (including cognitive and affective) processes" of an operator (Hardy & Parasuraman, 1997, p. 336). While this is a modern definition, the concept itself has a long history of research in psychology. The limits of human information processing were a hot topic of research during first half of the 20th century. Implicit in this research was the aspect of workload; that is, the load of task demands humans can effectively manage. Many classic articles concerning human limits were published at this point concerning perception and information processing (Miller, 1956), rational choice and decision making (Simon, 1955), psychomotor control (Fitts, 1954), vigilance (N. Mackworth, 1948), and others. These articles concerned basic cognitive, perceptual, and psychomotor functions, but later research on workload attempted to translate these human limitations to applied domains, such as aviation (Cooper & Harper, 1969; Monty & Ruby, 1965), process control (Singleton, Whitfield, & Easterby, 1967), and ground transportation (Brown, 1962; Brown & Poulton, 1961). Among other things, this research attempted to quantify the mental load experienced by operators, pilots, and other practitioners so that adverse working conditions could be predicted. Theoretical definitions and models of workload (Hancock & Meshkati, 1988; Moray, 1979) paralleled the empirical development of ways to measure and quantify workload (Cooper & Harper, 1969; Hart & Staveland, 1988; Knowles, 1963; Moray, 1982; Wierwille, 1979; Williges & Wierwille, 1979).

Workload transitions. In 1993, the National Research Council (NRC) committee on Human Factors called for research on workload transitions (Huey & Wickens, 1993; see also Howell, 1993; Wickens, 1991a). The term "workload transitions" was used to refer to the effects of prolonged low demand periods that rapidly transition to high demand situations. Later developments have come to consider both periods of prolonged high and low demands transitioning rapidly or gradually to the opposite demands. In essence, workload transitions concern the effects of changes in workload over time. To date, only a handful of studies have specifically investigated such effects with each study falling, roughly, into one of three different research approaches: hysteresis (Cumming & Croft, 1973), workload history (Cox-Fuenzalida, Swickert, & Hittner, 2004), and demand transitions (Krulewitz, Warm, & Wohl, 1975). The first research branch originated with Cumming and Croft (1973). This branch focuses on gradual changes in workload over time. The term "hysteresis effect" is used to describe the failure to return to previous performance levels during periods of decreasing task demands following a period of increasing task demands. In essence, the hysteresis effect states that an individual's previous workload experience impacts current performance. The second branch, starting with the work of Cox-Fuenzalida and colleagues in 2004, uses the term "workload history" rather than hysteresis and focuses on abrupt rather than gradual changes. The last branch was initiated by Krulewitz, Warm, and Wohl who in 1975 performed the first study to manipulate transitions in task demand during a monitoring vigil. This research branch has used the term "demand transition" rather than hysteresis or workload history to convey that the transition occurs in the task demands, which may not necessarily be associated with a transition in cognitive load. In the interest of being inclusive as well as providing common terminology, the phrase "workload transition" will be used to include all three prior lines of research.

It is important to note that these three tracks of research evolved relatively independent of one another. Traditionally, articles were only cited within branches. Only recently have articles referenced work *across* branches (Cox-Fuenzalida, 2007; Helton et al., 2008; Morgan & Hancock, 2011; Ungar, 2008). This has led to the parallel and isolated development of several theories and methods in that must now be considered collectively in future research on workload transitions. The following sections provide a historical overview of each of the three branches of workload transition research focusing on their respective theoretical frameworks. Due to the different research approaches employed there are multiple suggested explanations provided for various workload transition effects.

A note on terminology is required. Different authors use different terminology such as "easy versus hard," "low workload versus high workload," or "low signal salience (hard) versus high signal salience (easy)." Thus, to facilitate comparisons among studies, the terms "low" and "high" will be used throughout to refer to low task demands and high task demands, respectively. The abbreviation HL will be used for high-to-low transitions and LH for low-to-high transitions. Further, the term "task demand" is used rather than "workload" when properties of the task are described. The term "workload" is reserved for descriptions and measurements of an individual's reaction to task demands.

Hysteresis. The first study to outline the hysteresis effect was conducted by Cumming and Croft (1973). The hysteresis effect can be summarized as a performance decrement occurring during low task demands that is due to prior exposure to high task demands. Cumming and Croft replicated experiments conducted by Chamberlain (1968) and Croft (1971) using a task in which the rate of digit presentation started low, increased linearly until halfway through the trial, and then decreased linearly back to the original rate. Performance was measured by transmission rate; that is, the number of digits responded to correctly per second. Cumming and Croft (1973) noted that as the presentation rate increased, performance increased as well until it eventually leveled off under the higher presentation rate. However, when the presentation rate decreased again during the second half of the cycle, the transmission rate failed to return to the maximum level achieved previously. Cumming and Croft concluded that this performance decrement was due to the prior exposure to a higher rate, which they called the hysteresis effect.

To explain this effect, Cumming and Croft (1973) first reviewed two different hypotheses. The short-term memory (STM) overload hypothesis suggested that the performance decrease was due to STM overload at the higher presentation rate. This overload would persist for some time during the lower presentation rate thereby affecting those responses. Cumming and Croft rejected this hypothesis because the peak STM load should theoretically occur after performance has already started to decrease. Instead, Cumming and Croft favored a task expectancy hypothesis. Based on Gibbs' research

(1965; 1966; 1968) on the relationship between stimulus probability and response latency, this hypothesis stated that the participants expected the digit presentation rate to continue to increase or remain high, and thus failed to recognize that the rate was decreasing. This failure to recognize the demand transition would lead to an inappropriate response strategy, such as attempting to transmit only a subset of the signals rather than all signals.

Goldberg and Stewart (1980), M. Matthews (1986), and Farrell (1999) all sought to further investigate these two hypotheses. All three studies rejected the expectancy hypothesis because the hysteresis effect was still present even when cues indicating the current task demand level were presented to the operators. However, M. Matthews (1986) and Farrell (1999) suggested that this hypothesis could be modified using a strategic persistence explanation based on Poulton (1982). Poulton suggested an asymmetric transfer effect such that participants in a within-subjects design may inappropriately apply strategies learned in previous experimental conditions to subsequent conditions. This strategic persistence explanation states that participants may recognize the demand transition yet still persist in applying previously learned strategies. Posttransition performance may suffer when those strategies are not appropriate for the new task demand level (M. Matthews, 1986). Although Goldberg and Stewart (1980) supported the STM overload hypothesis, M. Matthews (1986) and Farrell (1999) rejected this hypothesis as well. M. Matthews showed that the hysteresis effect was present even in a task that did not rely on STM, and Farrell used a Model Human Processor simulation (Card, Moran, & Newell, 1983) to show that STM played a minimal role in the performance on the tasks used by Cumming and Croft (1973) and Goldberg and Stewart (1980).

The latest study on hysteresis was performed by Morgan and Hancock (2011; also Morgan et al., 2008). They defined hysteresis as a delayed reaction to changes in demand levels, and were interested in such hysteresis effects on subjective stress and workload. To study this, Morgan and Hancock used a simulated driving task that included a navigational aid. During the middle third of the driving scenarios, this aid was set to fail and the participants had to recite a 10-character alphanumerical code to an experimenter to restart the device. Thus, the first and last third of the scenario were classified as low-task demand (driving only) whereas the middle third was classified as high-task demand (driving and verbal report).This study can be considered qualitatively different from previous research in the hysteresis branch due to the use of an applied task as well as the workload transition manipulation. However, this research is foundational as it is the only study to date that has studied the hysteresis effect on mental workload and stress, and also the only study to look at workload and stress over time in a workload transition paradigm. The participants were prompted to use the Simplified Subjective Workload Assessment Technique (S-SWAT; Luximon & Goonetilleke, 2001) to verbally report their perceived levels of time pressure, mental effort, and stress at three points during the driving scenarios. The results of this experiment showed an increase in mean workload score from the first third of the drive (low demand) to the second (high demand). The last S-SWAT measurement was also significantly higher than the first, but not significantly different from the second. Each participant performed four consecutive scenarios and the same pattern of workload changes was found within each. Based on these results, Morgan and Hancock (2011) concluded that a hysteresis effect was present for subjective workload. That is, the participants' workload failed to return to the previous low level following a period of high workload within each scenario. Morgan and Hancock also concluded that the workload hysteresis effect must be mediated by STM because the higher workload at the end of one scenario did not carry over to the next scenario.

Workload history. The term, workload history, was first used by M. Matthews (1986) but Cox-Fuenzalida and her colleagues are the driving force in the workload history branch of workload transition research (Cox-Fuenzalida, 2007; Cox-Fuenzalida & Angie, 2005; Cox-Fuenzalida, Beeler, & Sohl, 2006; Cox-Fuenzalida, Swickert, & Hittner, 2004; Hauck, Snyder, & Cox-Fuenzalida, 2008). The primary contrast with hysteresis research is the use of sudden rather than gradual shifts in several different tasks.

Cox-Fuenzalida and her colleagues have generally found performance decrements in the minute immediately following both HL and LH transitions (Cox-Fuenzalida & Angie, 2005; Cox-Fuenzalida, Beeler, & Sohl, 2006), but also some evidence that LH shifts are associated with either a delayed effect (Cox-Fuenzalida, 2007) or a smaller effect (Cox-Fuenzalida, Beeler, & Sohl, 2006). This posttransition performance decrement has been found using different types of tasks, such as the Bakan vigilance task (Bakan, 1959), the Sternberg memory task (Sternberg, 1966), as well as in dual-tasking (Cox-Fuenzalida & Angie, 2005) and multi-tasking conditions (Hauck et al., 2008).

Cox-Fuenzalida and her colleagues have suggested multiple explanations for the workload transition effect. Cox-Fuenzalida and Angie (2005) appealed to mental resource theory (Kahneman, 1973; Wickens, 1984, 1991b; see also Wickens, 2008). Mental resource theory suggests theoretical, or metaphorical, information-processing resources that can be divided or allocated among tasks. The allocation of resources to a particular task is driven primarily by the demands of that task, and when a task demands more resources than can be allocated performance suffers. Cox-Fuenzalida and Angie suggest that a sudden workload transition may cause resource demands to exceed resource availability, thereby leading to a performance decrement. However, they do not explain why this would extend to an HL shift, where post-transition resource demands are, by definition, lower. Cox-Fuenzalida and Angie also suggest that the strategy persistence hypothesis offered by M. Matthews (1986) could explain the performance decrement; that is, the participants may fail to switch to a more appropriate strategy posttransition.

Cox-Fuenzalida and her collaborators have also discussed workload transitions with respect to stress. Cox-Fuenzalida et al. (2004) suggested that individuals high in trait anxiety would experience a greater stress reaction following a transition. This stress reaction would in turn impair performance, which would explain why trait anxiety predicts post-transition performance. However, Cox-Fuenzalida et al. did not measure subjective or physiological stress, leaving this connection purely hypothetical. Cox-Fuenzalida (2007) contrasted the strategic persistence hypothesis with the dynamic model of stress adaptation (Hancock & Warm, 1989). She suggested that "recuperative efforts" following a high-demand condition may interfere with performance. That is, following a period of high demand there would be a period of mental recovery during the low task demand condition which would result in decreased performance. Consequently, Cox-Fuenzalida (2007) predicted that strategic persistence would result in more errors of commission (i.e., false alarms; FAs) during low-workload trials. That is, if participants maintained a high effort strategy after the switch, they would display an increased rate of FAs. By contrast, if recuperative efforts are responsible for the performance decrement an increase in errors of omission (i.e., misses) should be seen instead as the participant tries to recover from the high workload. However, Cox-Fuenzalida found an increase in both error types following an HL transition. She interpreted this as support for the stress adaptation hypothesis over the strategic persistence hypothesis by suggesting that because the participants tried to recover mental resources, their response times might have been slowed so much that the responses were sometimes instead counted as commission errors.

Hauck et al. (2008) also studied subjective stress following a workload transition. They predicted that a workload transition, in either direction, would increase perceived stress and decrease performance but that social support would mitigate these effects. The results showed that, contrary to expectation, stress *decreased* rather than increased following an HL transition and was further alleviated by social support as well.

Demand transitions. Demand transitions represent the third major branch of workload transition research. This area was developed independently of the research on hysteresis and workload history from the first publication by Krulewitz, Warm, and Wohl (1975) until Helton et al. (2008) first referenced the workload history research. The primary difference from hysteresis and workload history research is that the demand transition research has focused on vigilance-type tasks.

The first study by Krulewitz, Warm, and Wohl (1975) was motivated by the lack of research on the effects of event rate transitions during vigilance experiments. They suggested two theoretical approaches to predict the effects of such transitions. First, the habituation model of vigilance (J. Mackworth, 1968, 1970a, 1970b) suggests that people habituate to the events presented during a task, which reduces the likelihood of signal detection. A higher event rate accelerates the habituation process leading to a more rapid decrement. However, any disruption to the established event rate would cause a dishabituation that would improve performance. According to habituation theory, demand transitions in any direction would lead to improved performance over a consistent level of demand. The second theoretical approach was expectancy theory (Colquhoun, 1960; Colquhoun & Baddeley, 1964; 1967). This theory states that when signal probability is held constant, a low as compared to high background event rate will lead to higher performance because the observer will have a greater expectancy that any given event is a signal. Observers who first experience a low event rate should maintain their expectancy of more signals per events, resulting in high performance in a second phase when the background event rate is increased. On the other hand, a shift from a high to a low event rate would imply that the observer expects fewer signals per event, leading to an increase in misses. In sum, an LH transition would produce superior performance relative to an unshifted high control, and an HL transition would produce inferior performance relative to an unshifted low control.

The results of Krulewitz et al.'s (1975) study showed that a change in event rate affected the participants' performance, but that neither theoretical position could readily explain the results. The transition did not increase performance as predicted by habituation theory, and the effect was in the opposite direction from that predicted by expectancy theory. Krulewitz et al. instead suggested that a contrast effect hypothesis may provide a better explanation. The contrast effect hypothesis was based on research by Hulse, Deese, and Egeth (1975), who showed a negative effect when participants are shifted from a "favorable" condition (i.e., one in which they could perform well) to an unfavorable condition. In such cases, the shifted participants' performance was inferior to those who experienced unfavorable conditions throughout the experiment.

There have been three subsequent studies designed to test this suggested contrast effect. Gluckman et al. (1993) found no support for the contrast effect hypothesis, and suggested instead that mental resource theory offers a better explanation for posttransition performance. Moroney et al. (1995) found limited support for the contrast effect hypothesis, but also found that mental workload ratings may differ significantly depending on the specific pattern of task demands and task demand transitions experienced by operators. The third study was performed by Helton, Shaw, Warm, G. Matthews, Dember, and Hancock (2004). They investigated both the contrast effect hypothesis as well as the effects of a workload transition on subjective reports of stress. The results showed that performance was superior for the low as compared to the high task demand condition both pre- and post-transition with no effect of the transition itself on task performance; thus, the contrast effect hypothesis was not supported. There were, however, effects of the transition on stress. Specifically, their study used the Dundee Stress State Questionnaire (DSSQ; G. Matthews et al., 1999; 2002), which divides stress into three different dimensions; task engagement, distress, and worry. Participants were more distressed in the transitioned than non-transitioned conditions. Further, participants reported higher task engagement in the LH condition compared to the non-transitioned controls, but lower engagement in the HL condition. Thus, Helton et al. concluded that demand transitions do not necessarily produce a contrast effect on performance but may affect subjective stress levels.

Helton et al. followed up on this research by investigating the effects of warned versus unwarned transitions on stress (Helton, Shaw, Warm, G. Matthews, & Hancock, 2008). They reasoned that a warning might alleviate the transition-induced stress response. They were motivated to study the effect of warnings by Miceli and Castelfranchi's (2005) argument that a key component of anxiety is "the anticipation of an indefinite threat, and the consequent uncertainty and wait" (p. 293). Helton et al. found that warned transition groups did not differ from the unwarned transition groups in terms of stress except for a decrease in task engagement in the warned LH group. Helton et al. suggested that a transition may increase an individual's uncertainty of future task demands, leading to an increase in distress. This explanation is based on the transactional stress theory (Lazarus & Folkman, 1984) and Miceli and Castelfranchi's (2005) research on uncertainty and anxiety. The changes in task engagement, on the other hand, were in line with the effort-regulation theory by Hockey (1993; 1997), which states that a person may voluntary regulate their effort based on perceived task demands.

The effort regulation theory and the mental resource theory (Kahneman, 1973) were further studied in workload transition research by Ungar et al. (2005) and Ungar (2008). These studies relied on a dual-task paradigm where one group performed a tracking and vigilance task concurrently during an induction phase, followed by the tracking task alone during a transition phase (Dual-Single; DS). A second group performed the tracking task alone throughout the two phases (Single-Single; SS). The overall difficulty of the tracking task was also manipulated using easy and hard conditions.

The results of Ungar et al.'s (2005) study showed that in the hard condition the performance of the SS group was superior to that of the DS group during both phases. In the easy condition, however, the performance of the DS group was superior to that of the SS group both before and after the transition. Ungar et al. argued that mental resource theory could explain the results in the hard condition, and effort-regulation theory the results in the easy condition. In the hard condition, performing the two tasks together depleted more mental resources than performing the tracking task alone, thereby lowering performance. This depletion then carried over into the transition phase such that the DS group had fewer mental resources compared to the SS group, resulting in lower performance by the DS group. In the easy condition, Ungar et al. argued that the DS group could have mobilized greater effort to cope with the demands of performing two tasks which then carried over to the transition phase, leading to superior performance compared to the SS group. Ungar (2008) replicated these results in a subsequent study. A second goal of Ungar's (2008) study was to replicate the posttransition stress effects found by Helton et al. (2004). However, Ungar found that task engagement declined and distress increased from pre- to posttask with no differences among transition groups or task difficulty conditions. Ungar concluded that the stress-related findings by Helton et al. (2004) did not extend to his study due to task specifics but did not elaborate further.

Summary of workload transition research. The literature on workload transitions can be divided into three branches of research based on their theories, methods, and cited previous work. The hysteresis branch has focused on short-term decrements in performance following HL transitions. The workload history branch has focused on performance decrements following both LH and HL transitions and using many different tasks. The demand transition branch has focused on vigilance-style tasks. This branch was initially focused on contrast effects, but later studies have focused more on effort regulation, resource depletion, and stress appraisals.

In terms of performance effects, general performance decrements have been found primarily in the workload history branch, following both HL and LH transitions (Cox-Fuenzalida, 2007; Cox-Fuenzalida & Angie, 2005; Cox-Fuenzalida et al., 2004; Cox-Fuenzalida et al., 2006; Hauck et al., 2008). Research in the demand-transition branch, on the other hand, has found either a performance decrement only following an LH transition (Gluckman et al., 1993; Krulewitz et al., 1975; Moroney et al., 1995) or no performance decrement at all (Helton et al., 2004; 2008). For these studies, the mental resource theory and effort regulation theory have been used to explain the results. Overall, this suggests that performance is generally robust to workload transitions and that any effects are likely of small magnitude.

Workload transitions seem to have a greater effect on subjective ratings of workload and stress than on performance. Cox-Fuenzalida et al. (2006) found that an HL transition group rated their workload higher than an LH group. Moroney et al. (1995), however, found complex interaction effects and cautioned that measuring subjective workload at the end of a task does not reflect a simple "average" workload over time. Rather, such ratings may vary depending on the pattern of task demand changes. The results of Morgan and Hancock (2011), who measured workload three times during task performance, support Moroney et al.'s urge of caution. Morgan and Hancock found that subjective workload ratings remained elevated following an HL transition, indicating a hysteresis-like effect following a transition possibly mediated by STM. Further, some researchers have found an increase in subjective stress (Helton et al., 2004; 2008) whereas others have found either a reduction in subjective stress (Hauck et al., 2008) or no effect (Ungar, 2008). At present, it is not clear why these studies arrived at such discrepant results. The most recent theoretical framework suggested, the transactional stress theory, may provide some guidance. This theory blends elements from the stress appraisal theory (Lazarus & Folkman, 1984), Hancock and Warm's (1989) adaptive stress model, Hockey's (1997) effort regulation theory, and G. Matthew's (2001) multi-dimensional stress framework.

STRESS

Definition. As a concept, stress must be treated carefully. The popular usage must be disentangled from the scientific definition (Stokes & Kite, 1994). Historical failure to do so has unfortunately led to the stress literature being flooded with confusing terminology (Hogan & Hogan, 1982). A prime example of this terminological confusion is the popular Yerkes-Dodson law, which has been alternatively portrayed as "the effects of punishment, reward, motivation, drive, arousal, anxiety, tension, or stress upon learning, performance, problem-solving, coping, or memory" (Teigen, 1994, p. 525) despite the fact that Yerkes and Dodson (1908) did not study *any* of those constructs. Although Hancock and Szalma (2008) noted that the manner in which Yerkes and Dodson's (1908) work has been misattributed and abused provides an important insight into how contemporary stress theories were developed, the purported law itself has been rejected by most contemporary stress theorists (e.g., Brown, 1965; Dekker & Hollnagel, 2004; Hancock, 1987; Hancock & Ganey, 2003; Hockey & Hamilton, 1983; Hancock & Warm, 1989; Koelega, Brinkman, & Bergman, 1986; Lacey, 1967; G. Matthews & Amelang, 1993; G. Matthews, Davies, & Lees, 1990; G. Matthews et al., 2010; Stokes & Kite, 1994; Teigen, 1994).

The current work will use Lazarus and Folkman's (1984) definition of stress. Lazarus pioneered the transactional perspective of stress research critical to contemporary stress theories (Folkman, et al., 1986; Lazarus, 1966; Lazarus, 1999). Lazarus and Folkman (1984) defined stress as "a relationship between the person and the environment that is appraised by the person as taxing or exceeding his or her resources and endangering his or her well-being" (p. 21). That is, stress comes from an active appraisal of the environment by the individual. Stokes and Kite (1994) emphasized the subjective nature of this appraising mechanism by saying that stress results from "a mismatch between an individual's *perception* of the demands of the task or situation, and his *perception* of the resources he has to cope with them" (p. 14, emphasis in original). This definition recognizes that a person may be stressed in a non-threatening situation and calm in a threatening situation depending on the person's perception of the situation. A further distinction of stress is between long-term or chronic stress, and acute stress. Acute stress is typically task-induced (Hancock & Warm, 1989), brief in duration, and likely to affect performance (Driskell & Salas, 1996). This work focuses on acute stress.

History of stress research. Early research on stress came from the physiological and medical domains. Cannon studied the effects of major emotions on bodily functions and homeostasis (Cannon, 1915; 1935). Deviations from homeostasis (i.e., abnormal bodily states) were called stress. Similarly, Selye defined stress as "the nonspecific result of any demand upon the body" (Selye, 1980, p. vii; 1936). The 'nonspecific results' were considered to be physiological in nature such that certain stimuli (termed stressors) would cause physiological changes (termed stress). These physiological changes became associated with arousal theory (Hebb, 1955) through the work of Broadhurst (1957; 1959). Broadhurst also referred to the work of Yerkes and Dodson (1908) as an example of how stressors affect arousal; a complete reinterpretation of Yerkes and Dodson's paper. This led to decades of the terms 'stress' and 'arousal' being used interchangeably in research. Hockey (1983), while rejecting this simplistic view of stress-as-arousal, noted that it has been a very influential theoretical perspective in stress research.

Historically, much research was focused on the stressors themselves; that is, the environmental elements that were thought to cause stress in individuals. Individual stressors were studied in detail; noise, for instance, is a widely studied stressor (Bower, Weaver, & Morgan, 1996; Broadbent, 1978; Davies & Jones, 1975; Jerison, 1959; Helton, Matthews, & Warm, 2009; Sanders & McCormick, 1993; Szalma, 2010; Szalma & Hancock, 2011), as is heat and cold (Hancock, 1986; Hancock, Ross, & Szalma, 2007; N. Mackworth, 1950), sleep deprivation or fatigue (Lieberman et al., 2002; Wilkinson, 1963), electrical shock, and many others (see e.g., Hancock, 1984; Wilkinson, 1969). However, the stressor-focused research often yielded conflicting results. The same stressor would sometimes result in a performance decrease and sometimes a performance increase. Some research participants classified a stimulus as stressful, whereas others did not. The sheer number of environmental elements that could potentially be considered stressors, their unpredictable interactions, and the great individual differences made a complete 'mapping' of absolute effects impossible (Hancock & Hall, 1990). Given that the same physical stimulus had different effects depending on person and context, it became clear that the *interpretation* of a stimulus by the individual was critical. This led to the appraisal approach to stress.

Transactions and appraisals. The concept of appraisal was introduced by Lazarus and Folkman (1984) as a potential explanation for the diversity of findings on stressor effects. Stress, they argued, is not a property of the stimulus itself. Rather, it is the result of a transaction between the stimulus and the interpreting mind. That is, a stimulus such as noise would not be stressful unless the person who experienced the noise appraised it as such. Specifically, they note that this is a cognitive appraisal which modulates the individual's reactions and behaviors.

In Lazarus and Folkman's (1984) theory, appraisal is divided into primary and secondary appraisal, although there is no fixed order between the two. Primary appraisal is the judgment of an encounter as either irrelevant, benign-positive, or stressful. Stressful appraisals can take on different forms: harm or loss, threat, challenge, or a combination of the three. If the encounter with a stimulus is judged to be irrelevant or benign-positive, the person would likely not experience stress. However, if the encounter is judged to cause harm or loss, is threatening (i.e., has the potential to cause harm or loss), or is challenging, the person might experience stress. The secondary appraisal concerns the reaction; that is, what might and can be done to alleviate the stressful encounter. In this phase the person would evaluate the strategies, coping mechanisms, potential consequences, and internal and external constraints in relation to the stimulus. Stress, Lazarus and Folkman argue, would result from a situation where the coping mechanisms are insufficient to alleviate the stressful stimulus. Another important aspect of Lazarus and Folkman's theory is the concept of re-appraisal. The appraisal is an ongoing process and the individual is constantly evaluating and re-evaluating their relation to the environment. Thus, appraisal must be considered as a process over time (Lazarus & Folkman, 1984; Lazarus, 1999).

G. Matthews (2001) has expanded upon the notion of transactions using different levels of explanation. Matthews argued that three conceptual levels can be constructed in which the transactions between the individual and the environment can take place: the physiological, the computational, and the goal-directed levels. In essence, this framework classifies different environmental stimuli as either acting upon the body (e.g., heat or cold), on the cognitive and computational functions of the individual (e.g., time pressure), or on the individual's goals and behaviors (e.g., performance criteria), or a combination thereof. One implication of this framework is that stressful transactions at one level may or may not affect the functioning of other levels. That is, we may experience stress cognitively without a physiological reaction, or experience a physiological reaction without an effect on our cognitive capacities. In the words of G. Matthews (2001), stress can act on multiple levels; from single-cell responses to complex decision-making.

Adaptive models of stress and effort. Lazarus and Folkman's (1984) model was mostly focused on stress in relation to major life events and over an extended period of time. By contrast, Hancock and Warm's (1989) adaptive stress model is oriented more toward task-focused, short-term stress. This model has also been called the "extended inverted-U model," because much like arousal theory it depicts stress level as the x-axis and physiological and psychological adaptability on the y-axis.

Hancock and Warm (1989) make the distinction between input-focused theories, (i.e., research on stressors), appraisal-focused theories such as Lazarus and Folkman's (1984) model, and output or reaction-based theories. Their model was specifically designed to span these different perspectives by considering the task at hand as the primary stressor to model the impact of stress on task performance. They note that performance can be maintained despite increases in stress, and argue that this results from adaptation. That is, individuals can adapt by increasing effort as the task places greater demands on the individual. As this adaptive capability is pushed to its limits, the individual will perform in a region of "dynamic instability" of hypo- or hyper-stress. Performance can be maintained for a short period of time, but may increase in variability, until the individual is no longer able to meet the task demands. The model accounts for both psychological adaptation, mainly through the investment of attentional resources, and physiological adaptation (i.e., maintenance of homeostasis).

Expanding on the notion of psychological and physiological adaptation, Hockey (1997) suggested a cognitive-energetic model of control regulation under stress and workload. The concept of effort is central in his model, as in Hancock and Warm (1989). Hockey distinguished between automatic and voluntary control of effort. The automatic control of effort concerns routine adjustments in effort in response to small changes in task demands. It is similar to the automatic processing of learned cognitive skills (Schenider & Chein, 2003; Schneider & Shiffrin, 1977) in that is requires little or no conscious thought or energetic cost. However, as task demands increase and the routine corrections made by the action monitor are insufficient to maintain target performance, the individual may *choose* to respond by increasing effort to reach the task goals.

However, the individual may instead choose to reduce the task goals to match the current performance. The goal adjustment function is important because increased effort is associated with an increased energetic cost; that is, mental or physiological resources consumed at a greater rate. Thus, the choice of engaging more effort in a task involves a cost-benefit trade-off between performance achievement and energy conservation. If energy conservation is more important than task performance the goals can be reduced rather than increasing effort.

The automatic effort adjustments correspond to Frankenhauser's (1986) notion of "effort without distress"; that is, the demands of the task may be high but the operator is able to maintain control. Effort without distress is characterized by task engagement and stable performance (Hockey, 2003). However, when task demands are high and effort controlled voluntarily the operator is in a state of "effort with distress" (Frankenhauser, 1986). That is, a state of mental strain and increased energetic expenditure. The effort associated with this mode of coping creates an aversive state associated with anxiety and rapidly increasing fatigue; in short, a state of stress. An alternative coping mechanism would be to adjust the task goal to match current performance and thereby conserve mental resources at the cost of reduced task performance. This corresponds to a state of "distress without effort" (Frankenhauser, 1986). While this task disengagement-type of coping conserves mental resources, it may still be associated with increased stress (Hockey, 2003).

The reviewed theories and models are mainly concerned with how stress arises and the resulting coping efforts and potential performance effects. However, they are less concerned with how stress manifests itself as a subjective or physiological experience or how to measure stress. The next section will outline ways to measure stress both subjectively and physiologically.

Measures of stress

Subjective measures. G. Matthews and his colleagues (G. Matthews et al., 1999; G. Matthews et al., 2000; G. Matthews, 2001) have argued that stress is not a unidimensional construct. That is, what is commonly referred to as "stress" can be separated into qualitatively different dimensions involving both mood and cognition. Examples of such dimensions are energetic arousal (mental states characterized by fatigue or vigor), hedonic tone (unpleasant versus pleasant mood states), and tense arousal (nervous or distressed states versus relaxed states). Based on this multidimensional approach, G. Matthews et al. developed the Dundee Stress State Questionnaire (DSSQ; G. Matthews et al., 1999; G. Matthews et al., 2002). The DSSQ is a subjective measure of stress addressing three different dimensions; task engagement, distress, and worry. The dimensions were derived through second-order factor analyses and are thus composed of several first-order factors (G. Matthews et al., 1999). Task engagement refers to a state of energetic arousal, motivation, effort, and concentration. It is characterized by task-focused coping and brought about by high cognitive demands and high effort. Distress, on the other hand, is characterized by tense arousal, a low hedonic tone (unpleasant mood), and low confidence and control. It is associated with emotion-focused coping and typically induced by high workload and threat. Finally, worry is associated with self-focused attention, low self-esteem, and cognitive interference (both task-related and task-unrelated). Worry is also associated with emotion-focused coping and avoidance. The different dimensions are associated with different types of appraisal and coping strategies.

The DSSQ has been widely used and validation studies have shown that different tasks and task demands result in different stress profiles along the three dimensions (G. Matthews et al., 1999; G. Matthews et al., 2002). The DSSQ has also been reduced to a shorter version, the Short Stress State Questionnaire (SSSQ; Helton, 2004; Helton & Garland, 2006). The SSSQ retains the same three higher-order dimensions as the DSSQ but has fewer questionnaire items.

Physiological measures. In addition to subjective measures there are also a number of physiological measures indicative of stress. Physiological stress measures include heart rate (HR) and heart rate variability (HRV; Aasman, Mulder, & Mulder, 1987; Nickel & Nachreiner, 2003; Vicente, Thornton, & Moray, 1987), electroencephalography (EEG; Fairclough & Venables, 2006; Kamzanova et al., 2011), galvanic skin response (GSR; Levin et al., 2006; J. Mackworth, 1968; Smallwood et al., 2004), cortisol levels (Almela et al., 2010; Amir et al., 2010; Dickerson & Kemeny, 2004; Frankenhauser et al., 1971), and eye tracking measures (e.g., pupil dilation and blink frequency; Hyönä, Tommola, & Alaja, 1995; Palinko et al., 2010).

Of all these different measures, the cardiovascular measures of HR and HRV have received support as a relatively non-intrusive, continuous stress measure while also being relatively easy and inexpensive to collect (Nickel & Nachreiner, 2003). Unlike the specialized equipment required for e.g. EEG or GSR, heart rate monitors (HRMs) that measure beat-to-beat intervals necessary for HRV analysis are available to private consumers in the form of sport watches. High-end commercially available sport watches have been shown to be a valid tool to collect and analyze HR and HRV data (Gamelin, Berthoin, & Bosquet, 2006; Goodie, Larkin, & Schauss, 2000; Sætrevik, 2012).One of the main limitations of commercial HRMs is the reduced sensitivity, which makes them unsuitable for populations that require sensitive measurement equipment, (e.g., women over the age of 60;Wallén et al., 2012). Despite their limits, commercial HRMs may be justified by the increased portability, flexibility, and their low cost. This is of particular importance in applied settings where HR and HRV data are wanted, such as for pilots flying a plane (Wilson, 2002), air traffic controllers (Langan-Fox, Sankey, & Canty, 2011) and military Survival, Evasion, Resistance, and Escape (SERE) training (Taylor et al., 2007).

The primary difference between HR and HRV is that HR is essentially an average of heartbeats over time whereas HRV measures each beat-to-beat, or R-R, interval separately. Thus, HRV data can be used to extract the sympathetic and parasympathetic activation of the heart. Stress is typically associated with an increase in sympathetic activation, a decrease in parasympathetic activation, or a combination thereof (Berntson & Cacioppo, 2004). Using a power spectral density analysis, such as an autoregressive model (AR) or Fast Fourier Transformation (FFT), the powers of different frequencies of cardiac control can be extracted from the R-R data. The Low Frequency (LF) band (0.06 Hz to 0.14 Hz) is associated with increased sympathetic activation. This band is sensitive to workload and time pressure (Aasman, Mulder, & Mulder, 1987; Berntson & Cacioppo, 2004; Ewing & Fairclough, 2010; Kamada et al., 1992; Miyake et al., 2009) and invested effort (Aasman, Mulder, & Mulder, 1987; Fairclough & Roberts, 2011; Vicente, Thornton, & Moray, 1987), but not necessarily other manipulations such as incentive

(Ewing & Fairclough, 2010). Typically, the amplitude (power) of the LF band decreases with increased task demands and increased effort. Although other HRV measures have been used in the past, such as the ratio of LF to Very Low Frequency (VLF; 0.00-0.04 Hz) or ratio of HF to Total Power (TP; 0.00-0.4 Hz), these have received less support as valid measures of stress (Garde et al., 2002; Miyake et al., 2009). LF HRV has received more support as a measure of mental strain and effort than HR and other frequencies of HRV whereas HR is more sensitive to physical and emotional strain (Boucsein & Backs, 2000). Thus, in tasks that involve a combination of physical, mental, and emotional strain, such as piloting an aircraft, HR may be a more sensitive measure of overall task demands than HRV (Wilson, 2002), but in tasks that does not require physical effort and place greater weight on cognitive rather than emotional strain, LF HRV may be more sensitive.

The only study using physiological measures of stress to study workload transitions was conducted by Cerruti et al., (2010). In their research, they found that additional physiological resources, as measured by Transcranial Doppler (TCD) and electrocardiographic (ECG) data, were required following a workload transition. Unfortunately, due to a small sample size (3 participants) and lack of performance differences between workload conditions few conclusions could be drawn from their research. However, their approach motivates the use of physiological stress measurements in workload transition research.

Summary of stress research. The appraisal perspective of stress outlined by Lazarus and Folkman (1984) is the underlying foundation for later theoretical developments such as Hancock and Warm's (1989) adaptive stress model and Hockey's

(1997) effort regulation model. According to this perspective, stress is the result of a transaction between individuals and their environment. The key is the active appraisal and re-appraisal by the individual, meaning that stress arises when a stimulus is appraised by that individual as taxing or exceeding his or her coping ability. The re-appraisal aspect emphasizes that the stress appraisal mechanism is a continuous process, meaning that an individual's stress response to the same stimuli may change over time. The adaptive stress model is concerned with acute stress induced by the task at hand rather than general long-term life-stress and focuses on the psychological and physiological adaptation by the individual. The effort regulation model provides further details on the adaptive process by accounting for voluntary control of effort and goals. The model emphasizes that the individual may voluntarily respond to increased external load through increased effort but may also choose to instead conserve effort and lower their task goals. The appraisal perspective, the adaptive stress model, and the effort regulation model all blend well together to account for how stress arises from appraised task demands, and the different coping reactions used to alleviate stress. In previous workload transition studies, these various theories, models, and frameworks have been included under umbrella terms such as "transactional model" (Helton et al., 2008), "transactional approach" (Ungar, 2008), and "adaptation-based theory" (Cox-Fuenzalida, 2007). In the current work the term transactional stress theory will be used as the umbrella term for the appraisal perspective, the adaptive stress model, and the effort regulation model.

CHAPTER III

EXPERIMENT 1

The current work was concerned with the effects of workload transitions on stress. Transactional stress theory was used to guide the research as it is currently the theory that best accounts for the effects of workload transitions and corresponding stress reactions (Cox-Fuenzalida, 2007; Helton et al., 2004; 2008). To date, there have been five studies that investigated stress in conjunction with workload transitions: Hauck et al. (2008), Helton et al. (2004; 2008); Morgan and Hancock (2011), and Ungar (2008). Hauck et al. (2008), however, professed to have used a problematic experimental design and their results will not be considered further. Helton et al. (2004; 2008) found that participants who experienced a workload transition had increased ratings of distress. They suggested that a transition may increase the uncertainty of future task demands, thereby increasing distress for individuals as they appraise imposed task demands and their own coping ability. Helton et al. (2008) also found that task engagement increased following an LH shift, but decreased following an HL shift. In context of Hockey's (1997) effort regulation theory, it appears that the participants attempted to match their effort to the new task demands by engaging more in the task when faced with higher task demands and less when faced with lower demands. Morgan and Hancock (2011) found that subjective stress remained elevated during a brief period of low workload that was preceded by high workload. This result is consistent with Helton et al.'s (2004; 2008) suggestion that participants would be uncertain of future task demands following a transition, and as a result report increased stress. Ungar (2008), however, found that participants rated their distress higher at the end of a vigilance-type task and that task engagement declined over time with no effect of workload transition. Ungar speculated that Helton et al.'s results may not have been replicable in his experiment due to differences in the tasks used but did not elaborate further.

In summary, the workload transition research to date shows discrepant findings on stress. Consequently, the primary goal of the current work was to search for a unifying explanation of the differences. It was hypothesized that the concept of an appraisal process in the transactional stress theory would offer a simple yet powerful explanation of the discrepancies. That is, because stress results from a continuous appraisal process, stress measurements could produce different, even conflicting, results if the time course of the transition is not taken into account. This factor has not been previously controlled or manipulated, which has led to a wide range of measurement timings in the past research; from immediately posttransition (Morgan & Hancock, 2011) to 6 minutes posttransition (Helton et al., 2004; 2008) to 20 minutes posttransition (Ungar, 2008). It is possible that Ungar was unable to find transition effects because the participants had adjusted to the new level of task demand by the time they were assessed. Thus, the first experiment attempted to explain the discrepant results from previous studies by investigating changes in stress over time following a transition.

HYPOTHESES

Experiment 1 investigated the effects of workload transitions on subjective and physiological stress over time. Three sets of hypotheses are suggested. The first set concerns the direct effects of a workload transition on stress immediately following a transition. The second set concerns changes in stress over time. The third set concerns changes in task performance following a workload transition.

Immediate stress effects. A transition in task demands should be accompanied by a re-appraisal of the task by the individual. This re-appraisal may lead to an increase in stress as the individual attempts to determine whether the new task demands exceed his or her coping ability. As measured by the SSSQ, this should manifest itself as an increase in the distress dimension, which is associated with overload, tension, and perceived control. Although this increase in distress should be evident in both HL and LH transitions, the increase in the LH condition may be driven by the new task demands themselves. In the HL condition, however, the new task demands are lower and an increase in distress should be driven solely by the transition itself.

Distress increase hypothesis: A transition in task demands in either direction is associated with an increase in distress compared to nonshifted controls.

According to the transactional stress theory, individuals may use a task-oriented coping strategy to respond to increased stress by adjusting their level of effort. An HL shift should therefore be associated with decreased effort and an LH shift with increased effort. This change in effort should be reflected in the task engagement dimension of the SSSQ as well as subjective reports of effort on the NASA TLX and a custom post-experiment questionnaire (described later). The current experiment will also use low frequency (LF; 0.04-0.15 Hz) HRV power to measure physiological responses because it is sensitive to cognitive strain and effort. Thus, the HRV measurement should further corroborate the subjective effort measurements.

Effort regulation hypothesis: An increase in task demands is associated with increased task engagement and effort. A decrease in task demands is associated with decreased task engagement and effort.

An alternative to the effort regulation hypothesis is that an individual changes his or her goal levels. According to Hockey's (1997) effort-regulation theory an individual may choose to change their performance goals rather than their effort level. Thus, an LH transition may result in maintained effort levels and reduced performance goals. An HL transition may lead to increased goals and maintained high effort. Subjective reports of personal goal levels will be collected through a custom postexperiment questionnaire (described later).

Goal regulation hypothesis: An increase in task demands is associated with lowered self-reported performance goals and a decrease in task demands is associated increased self-reported performance goals.

Stress effects over time. Whereas the previous set of hypotheses concern the immediate effects of a workload transition, this set focuses on changes in stress over time. Transactional stress theory emphasizes that stress is a result of a continuous appraisal process (Lazarus & Folkman, 1984). In the case of a workload transition, this would mean that over time the level of stress experienced would be driven by the new task demands rather than the transition itself. In other words, participants should acclimate to the new task demands, and not maintain an elevated stress level for an extended period of time. Thus, the experienced stress of an HL transition group should approach the levels exhibited by an LL control group posttransition, whereas an LH group should approach an HH control group. This should also hold for estimates of workload, as the reappraisal process concerns the perceived demands, i.e. workload.

Continuous appraisal hypothesis: Transitioned groups will approach nontransitioned control groups over time on measures of stress and workload.

An alternative hypothesis based on Morgan and Hancock's (2011) research is that the stress and subjective workload levels of an HL transition group will remain elevated compared to a control LL group. Morgan and Hancock explained this hysteresis effect by a short-term memory overload as they found that it lasted only a few minutes. Thus, the effect should be evident in close temporal proximity to the transition but not later in measurements.

Hysteresis hypothesis: An HL transition group should remain elevated on measures of stress and workload as compared to a nontransitioned LL control group.

Performance hypotheses. The most relevant theories pertaining to performance effects are the effort regulation theory and the mental resource theory. The effort regulation hypothesis states that groups transitioned from one level of workload to another will adjust their effort accordingly by increasing their effort following an LH transition and lower their effort following an HL transition. This hypothesis has two components: the adjustment of effort and the resulting change in performance. Previous researchers who have suggested or supported the hypothesis did not measure or control for effort or goal level (e.g., Helton et al., 2008; Ungar, 2008). The current experiment will address all components of the theory by measuring performance, effort, and performance goals. The changes in effort and goal levels are captured in the effort regulation and goal regulation hypotheses. The current hypothesis then concerns the performance effect associated with those changes in effort and goals.

Effort-performance relation hypothesis: Increased effort and higher goals are associated with higher performance whereas decreased effort and goals are associated with lower performance.

Mental resource theory predicts that performance varies depending on the availability of mental resources. Higher task demands deplete mental resources more quickly than lower task demands. Thus, the posttransition performance of an LH group should be superior to that of an HH group.

Mental resource hypothesis: The posttransition performance of an LH group will be superior to that of an HH group. The posttransition performance of an HL group will be inferior to that of an LL group.

METHOD

Participants. A power analysis was conducted using data from a pilot study with 32 participants. The power analysis used a power of 0.8 as recommended by Cohen (1992) and partial η^2 of 0.103, which gave an estimated total sample size of 72 divided over the four conditions. Thus, 72 undergraduate students from Old Dominion University were recruited to participate in this study. The participants had normal or corrected-to-normal vision and were 18 years or older. Further, participants were screened for allergy to latex or gels due to the use of the heart rate measuring equipment. The participants were recruited through the SONA online participant management system and compensated with course credits for their participation.

Task. This experiment used a version of the Bakan vigilance task called the Rapid Information Processing (RIP) task (G. Matthews & Campbell, 2009; Wesnes & Warburton, 1983). This task requires observers to view random digits briefly presented on a screen. The observer is asked to press the spacebar when they detect a series of three odd or three even digits in sequence. To count as a hit, the spacebar had to be pressed within 1.2 seconds of the last digit in a target sequence. The digits were black presented on a white background with each digit shown for 125 ms. The digits were 8 mm vertically by 5 mm horizontally in size and viewed from a distance of approximately 0.5 meters, although the participants were free to adjust the screen and their own posture. Two different levels of task demand were used: low (30 events/minute) and high (120 events/minute). The signal probability was kept constant at 13.33%, resulting in 4 and 16 signals per minute, respectively, in the two event rate conditions.

Task performance. Task performance was measured by perceptual sensitivity (d'; Green & Swets, 1974) and response bias (C; Snodgrass & Corwin, 1988). The measure of d' was calculated by subtracting the standardized false alarm rate from the standardized hit rate. Larger values of d' indicates greater perceptual sensitivity, i.e. ability to discriminate signals from nonsignals. The measure of response bias was calculated by adding the standardized false alarm rate to the standardized hit rate and multiplying by 0.5. Positive C values indicate conservative response bias and negative values liberal. A C score of 0 indicates neutral bias. Perfect hit rates of 1 (17 out of 216 data points) were reduced by 0.001 and false alarm rates of 0 (31 out of 216 data points) were increased by 0.001 to enable calculations of d' and C.

Subjective measures. The SSSQ was used as a subjective measure of stress. The SSSQ was analyzed in terms of three higher-order factors: task engagement, distress, and worry. The three factors have internal reliability with a Cronbach's α of .81, .87, and .84, respectively (Helton, 2004). The NASA TLX (test/re-test reliability .77 to .83; Battiste & Bortolussi, 1988; Hart & Staveland, 1988) was used to collect ratings of workload in terms of mental and temporal demands as well as subjective estimates of performance, effort, and frustration. Only the ratings of mental demands, temporal demands, and effort are of interest in the current study.

A 9-item posttask questionnaire (Appendix A) was also administered. Question 1 concerned the participants' overall impression of the task. The response options consisted of 15 categorical descriptions (e.g., boring, threatening, hard, easy, unpredictable, predictable, demanding, etc.) and the participant was asked to rate how well each one described the task from 1 (a little) to 5 (very much), or leave blank if the description was not applicable. The key categories for the current experiment are the "easy" and "hard" categories, which will be used as a manipulation check that the HH condition was perceived as hard and the LL condition as easy. Other negative descriptors (taxing, exhausting, demanding, draining, and stressful) are also likely to be associated with the HH condition over the LL condition but not of interest in the current study.

Questions 2, 3A, and 3B concerned the detection of a transition. Question 2 asked the participants to rate whether the task difficulty remained consistent throughout the experiment on a 5-point Likert scale (completely disagree to completely agree). Question 3A then asked the participant if there was any clearly noticeable change in the task. Examples include "yes, the digits changes color," "yes, the digits sped up," "yes, the digits slowed down," and "yes, the digits grew larger." An option "no, the task did not change" was also included. For the current experiment, the three relevant options are the negative statement ("no, the task did not change") and the two items concerning a change in digit presentation speed. Question 3B asked the participant to rate how easy or hard it was to notice the change using a 5-point Likert scale (very easy to notice to very hard to notice).

Items 3C through 3E concerned the participants' reaction to the transition. These items were included to test the predictions based on effort regulation theory. Question 3C concerned the overall profile of the task and consists of the same 15 statements from Question 1 in comparative form (e.g., "more boring," "more draining," "harder," "easier") as well as an option of "none of the above." This question concerned the individual's perception of different task qualities following the transition. Question 3D asked about the participants' change in effort following a transaction using two 5-point Likert scales ("Low Effort" to "High Effort"). The first Likert scale concerned the participants' level of effort before the transition whereas the second scale concerned the effort level after the transition. Question 3E similarly asked about the participants' goal level using two 5-point Likert scales ("Low Goal" to "High Goal"). The endpoints were further anchored by defining a low goal as aiming to "catch no or a few signals" and a high goal as aiming to "catch all signals." Question 4 asked the participants who did not notice a transition to describe how the task changed over time. It used the same response options as question 3C. Finally, question 5 was an open-ended question prompting the participants for any other opinions or thoughts on the task or experiment in general.

Physiological measures. Cardiovascular data were collected using a Polar RS800CX HR monitor sports watch. The RS800CX is currently the latest high-end model of the Polar brand that has been used in previous validation studies (Gamelin et al., 2006; Goodie et al., 2000; Wallen et al., 2012) and stress research (Sætrevik, 2012). The RS800CX recorded the beat-to-beat intervals with a temporal resolution of 1 ms. This HRV data was analyzed using the Kubios software (Niskanen et al., 2002) developed by the Biomedical Signal Analysis Group at the University of Kuopio, Finland. The data were analyzed in terms of power spectral density (PSD) by using an autoregressive model (AR) to extract the low-frequency (LF) HRV power for each period of task performance.

Procedure. The participants were assigned at random to either one of the two control groups (HH or LL) or two experimental groups (HL or LH). Sex was balanced across groups. The participants first completed an informed consent form and demographics questionnaire, and were then given detailed task instructions and fitted with the HRM equipment. This is shown as "Pre-Experiment" in Figure 1.

Group	Pre-Experiment	Break	Q1	Min 1-6	Min 7	Q2	Min 8-12	Q3	Min 13-18	Q4	Q5
HH	Instructions, HR Equipment	10-min rest	Pre-Task SSSQ	High	High	F1	High	F2	High	F3	Post-Experiment
HL					Low		Low		Low		
LL				Low	Low		Low		Low		
LH					High		High		High		

Figure 1. Experimental conditions and task sequence. Q indicates questionnaires. F indicates freeze-probes, which consists of both the SSSQ and the TLX

The instructions included examples of how the digits were to be presented with the signals clearly marked. However, the participants were not told about the digit presentation rate or that it could change during the task. They were also given instructions on how to complete the SSSQ and TLX. The participants were asked to surrender their watches and cell phones for the duration of the experiment. Following the instructions, the participants were moved to a sound-attenuated booth where they performed the rest of the experiment. The experiment started with a 10-min rest period ("Break" in Figure 1) to let the participants settle and to collect baseline cardiovascular data. The participants were instructed to remain seated in their chair and relax with their eyes open during this period. After the rest period, the participants completed a pre-task SSSQ, "Q1". This SSSQ was used to collect baseline ratings of task engagement, distress, and worry. After completing the questionnaire the participants engaged in an 18-min task session. The HH and HL groups started the task at high workload, and the LL and LH groups at low. The two transition groups transitioned to the opposite task demand level at the end of the 6^{th} minute. This transition is shown in Figure 1 in the change between "Min 1-6" and "Min 7." Combined SSSQ and TLX probes were administered at the 7-min ("Q2"), 12-min ("Q3"), and 18-min ("Q4") mark. Upon completing the test session, the participants filled out the post-experiment questionnaire, "Q5."

Experimental design. This experiment used a basic split-plot design. There were two between-groups variables; task demands and transition. Task demands refer to the task demands that the participants started with at the onset of the experiment. This variable has two levels; high and low. Transition refers to whether the participants were transitioned to the opposite task demand level or remained at a constant level.

A third component of the experimental design was the within-subjects variable of time. The SSSQ and TLX data were collected using probes administered at the end of the

7th, 12th, and 18th minutes, referred to as probe 1, 2, and 3, respectively. Thus, in terms of those dependent variables a 2 (task demands) by 2 (transition) by 3 (probe) design was used. Performance and HRV data were collected for each minute of task performance and summarized across the periods; period 1 (minutes 1 through 6), period 2 (minutes 7 through 12), and period 3 (minutes 13 through 18). Thus, these dependent variables used a 2 (task demands) by 2 (transition) by 3 (period) design.

EXPERIMENT 1 RESULTS

Participants. Seventy-five participants took part in the experiment. Three participants were removed prior to analysis due to either a complete lack of task responses (0% hit, 0% FA; two participants) or failure to follow the instructions (one participant). The resulting sample of 72 participants consisted of 20 male and 52 female students with a mean age of 25.11 years (SD = 8.06) and sex balanced across the experimental conditions.

Data treatment. The data were checked for outliers and any extreme values (>3 inter-quartile ranges from the mean) were Winsorised by replacing the outlier with the 95th or 5th percentile value. Skewness, kurtosis, normality, and homogeneity of variance were assessed prior to analysis. Although violations were detected for some variables, the planned analyses were considered robust against those violations given the size and even distribution of the sample over the different groups (Maxwell & Delaney, 2004). Greenhouse-Geisser corrections were applied for all statistical tests where Mauchly's test of sphericity was significant. In the cases where the corrections did not alter the interpretation of the test the uncorrected F-string is reported, otherwise the corrected F-string is reported.

The SSSQ pretask scores were assessed for differences among any of the four groups using separate 2 (task demands; high, low) by 2 (transition; no transition, transition) ANOVAs on task engagement, distress, and worry. There were no initial differences among the groups for any of the three variables ($p > .3$ in all cases). The SSSQ scores were therefore normalized on the overall pretask scores for each scale and then converted to individual change scores by subtracting the individual's pretask score from their subsequent scores (probes one through three). Physiological data for four participants were lost due to equipment failure. There were no differences for LF HRV power in the resting baseline data across any groups ($p = .196$). The physiological data were converted to individual change scores by subtracting the 10-minute resting baseline of each individual from each subsequent data point.

The hit rate and false alarm rates for each participant were averaged over the three task periods. The first period encompasses the time before the transition, the second period represents the six minutes immediately after the transition, and the third period is the last six minutes of the task. Signal detection measures of d' and C were calculated on these aggregate scores to provide measures of perceptual sensitivity and decision bias, respectively.

Unless otherwise noted, the general analytical approach used a 2 (task demands) by 2 (transition) by 3 (probe or period) split-plot ANOVA. Significant three-way interactions were followed up by 2 (task demands) by 2 (transition) ANOVAs at each probe and 3 (probe or period) repeated measures ANOVAs for each group. Pairwise comparisons using Tukey post hoc tests were used to explore significant between-group interactions and significant effects of probe or period across the three levels.

Posttask questionnaire data. One-tailed t-tests on the posttask questionnaire data showed, as expected, that the HH group rated the task as harder, more challenging, more demanding, and more stressful than the LL group (all $p < .017$). The constant control groups also agreed more with the statement that the task demands remained consistent throughout the experiment than the transition groups, $t(70) = 5.964$, $p < .001$. The complete data set from the posttask questionnaire can be found in Appendix C.

Stress

Distress. The ANOVA for distress showed a significant main effect of probe, a task demands by transition interaction, a probe by task demands interaction, and a three-way interaction, see Table 1.

Table 1.

Exp. 1 Analysis of Variance for Distress

Source	Type III SS	df	MS	F	p	η_p^2
Within-Subjects Effects						
P	5.827	2	2.913	3.897	.023	.054
P X D	23.643	2	11.821	15.811	.000	.189
P X T	.429	2	.214	.287	.751	.004
P X D X T	16.759	2	8.379	11.207	.000	.141
S X P (D X T)	101.683	136	0.748			
Between-Subjects Effects						
D	15.126	1	15.126	2.754	.102	.039
T	8.240	1	8.240	1.501	.225	.022
D X T	95.495	1	95.495	17.390	.000	.204
S (D X T)	174.729	68	5.491			

Note. D = (Task) Demands, T = Transition, P = Probe.

The means for the four groups are shown in Figure 2. The ANOVA at probe one showed a significant main effect of task demands, $F(1, 68) = 23.142, p < .001$, partial $\eta^2 = 0.254$, such that the groups who received high task demands had significantly higher distress (M = 1.673, SD = 1.723) than those who received low task demands (M = 0.218, SD = 0.666).

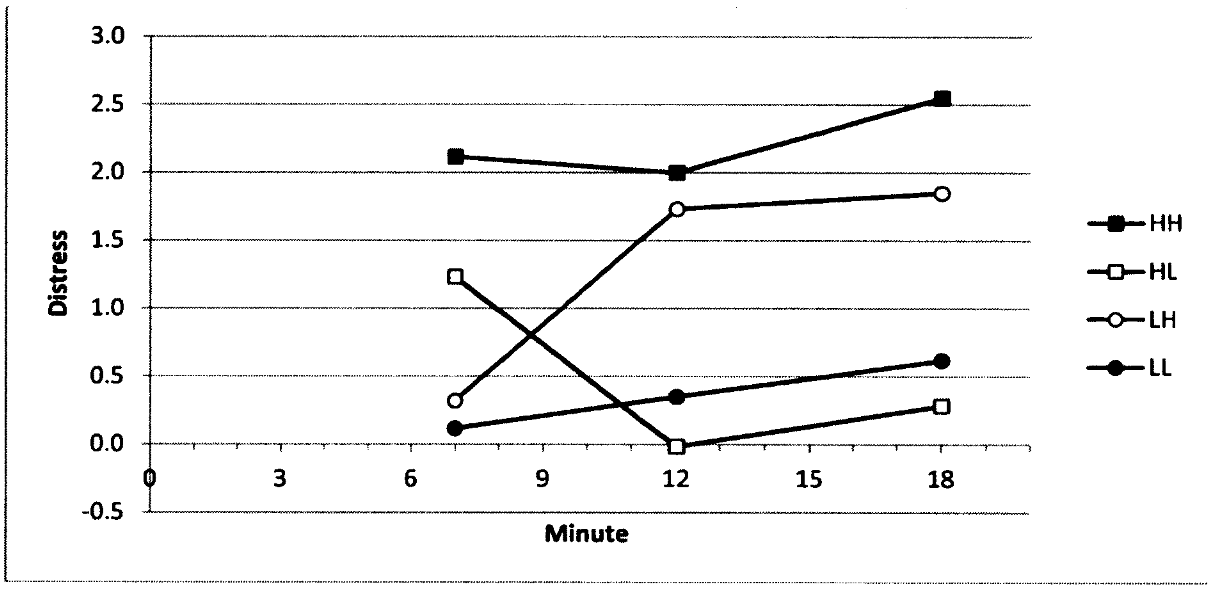

Figure 2. Exp. 1, standardized distress change scores across the three probes.

The ANOVA at probe two showed a significant task demands by transition interaction, $F(1, 68) = 22.201, p < .001$, partial $\eta^2 = 0.246$, such that the HL group had significantly lower distress (M = -0.017, SD = 0.441) than the HH group (M = 1.998, SD = 2.377) but the LH group had significantly higher distress (M = 1.732, SD = 1.756) than the LL group (M = 0.350, SD = 0.652). Further, the LL group had lower distress than the HH group, and the HL lower than the LH group.

The ANOVA at probe three showed the same pattern as probe two. A significant task demands by transition interaction, $F(1, 68) = 18.340$, $p < .001$, partial $\eta^2 = 0.212$, such that the HL group had significantly lower distress (M = 0.283, SD = 0.779) than the HH group (M = 2.547, SD = 2.539) and the LH group (M = 1.848, SD = 1.998). Further, the LL group (M = 0.616, SD = 0.978) had lower distress than the HH group, and the HL lower than the LH group.

The repeated measures ANOVA on distress over the three probes for the HH group revealed no significant changes over time, $F(2, 34) = 1.897$, $p = .166$, partial $\eta^2 = 0.100$. For the LL group there was a significant effect, $F(2, 34) = 4.514$, $p = .018$, partial $\eta^2 = 0.210$, such that the distress score increased from probe one (M = 0.117, SD = 0.494) to probe three (M = 0.616, SD = 0.978). The HL group showed a significant change over time, $F(2, 34) = 8.526$, $p = .001$, partial $\eta^2 = 0.334$, such that the distress score decreased from probe one (M = 1.232, SD = 1.701) to probe two (M = -0.017, SD = 0.441). There was also a significant effect for the LH group, $F(2, 34) = 12.435$, $p < .001$, partial $\eta^2 = 0.422$, such that the distress score increased from probe one (M = 0.319, SD = 0.904) to probe two (M = 1.732, SD = 1.756).

Task engagement. The ANOVA for task engagement showed main effects of task demands and probe, a task demands by transition interaction, and a task demands by transition by probe interaction, see Table 2.

The means for the four groups are shown in Figure 3. The ANOVA at probe one showed a significant main effect of task demands, $F(1, 68) = 12.494$, $p = .001$, partial $\eta^2 = 0.155$, such that the groups who received high task demands had significantly lower task engagement (M = -0.404, SD = 1.050) than those who received low demands (M = 0.371, SD = 0.805). No other effects reached significance.

Table 2.

Exp. 1 Analysis of Variance for Task Engagement

Source	Type III SS	df	MS	F	*p*	η_p^2
			Within-Subjects Effects			
P	12.477	2	6.239	15.813	.000	.189
P X D	1.276	2	0.638	1.617	.202	.023
P X T	0.112	2	0.056	0.142	.868	.002
P X D X T	4.299	2	2.150	5.448	.005	.074
S X P (D X T)	53.657	136	0.395			
			Between-Subjects Effects			
D	18.341	1	18.341	7.138	.009	.095
T	0.212	1	0.212	0.083	.775	.001
D X T	29.685	1	29.685	11.553	.001	.145
S (D X T)	174.729	68	2.570			

Note. D = (Task) Demands, T = Transition, P = Probe.

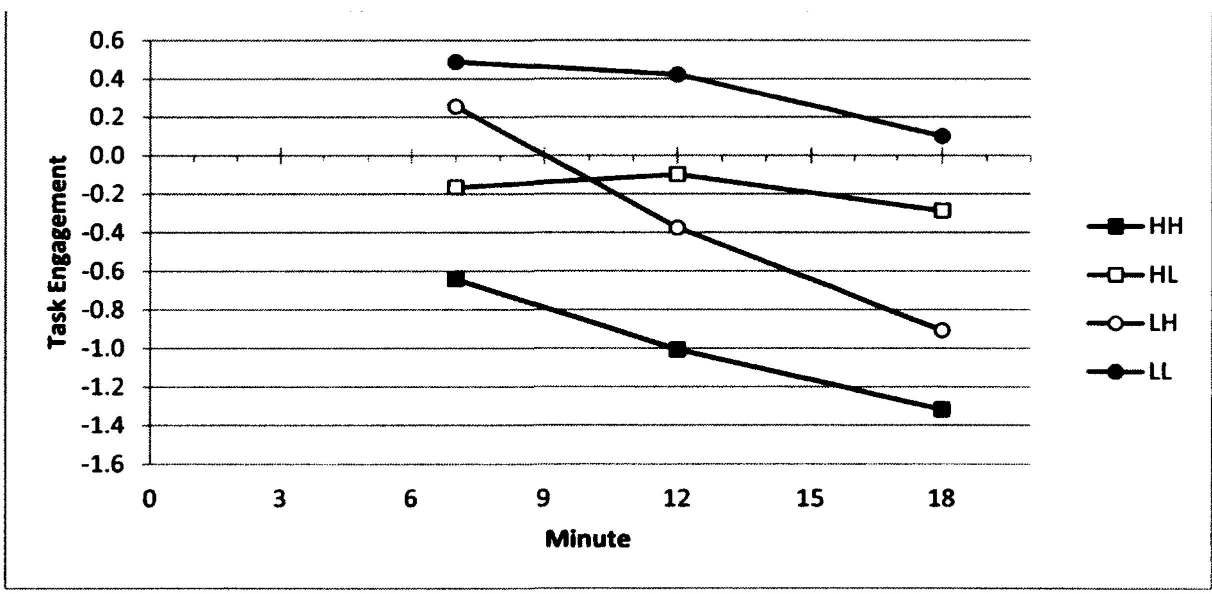

Figure 3. Exp. 1, standardized task engagement change scores across the three probes.

The ANOVA at probe two showed a significant main effect of task demands, $F(1, 68) = 4.975$, $p = .029$, partial $\eta^2 = 0.068$, and a task demands by transition interaction effect, $F(1, 68) = 10.910$, $p = .002$, partial $\eta^2 = 0.138$. The interaction was such that the LL group had significantly higher task engagement (M = 0.421, SD = 0.742) than the HH group (M = -1.007, SD = 1.485) but there were no differences among any other groups.

The ANOVA at probe three showed a significant task demands by transition interaction, $F(1, 68) = 14.394$, $p < .001$, partial $\eta^2 = 0.175$, such that the HL group had higher task engagement (M = -0.288, SD = 0.752) than the HH group (M = -1.317, SD = 1.405) but the LH group (M = -0.907, SD = 1.459) had lower task engagement than the LL group (M = 0.010, SD = 0.717). The HH group also had lower task engagement than the LL group.

A repeated measures ANOVA on task engagement over the three probes for the HH group revealed a significant change over time, $F(2, 34) = 3.951$, $p = .029$, partial $\eta^2 = 0.189$, such that the task engagement declined from probe one (M = -0.642, SD = 1.090) to probe three (M = -1.317). Regarding the LL group, there was a significant effect, $F(2, 34) = 4.323$, $p = .021$, partial $\eta^2 = 0.203$, such that the task engagement score decreased from probe one (M = 0.4869, SD = 0.498) to probe three (M = 0.010, SD = 0.717). There was no significant change over time for the HL group, $F(2, 34) = 0.355$, $p = .704$, partial $\eta^2 = 0.020$. For the LH group there was a significant effect, $F(2, 34)= 14.563$, $p < .001$, partial $\eta^2 = 0.461$, such that the task engagement score decreased from probe one (M = 0.255, SD = 1.029) to probe two (M = -0.376, SD = 1.112) and from probe two to probe three (M = -0.907, SD = 1.459).

Heart rate variability. The ANOVA for HRV showed a significant effect of time only, see Table 3. This effect was such that the HRV increased across all groups from time period one (M = -492.131, SD = 543.006) to period two (M = -227.011, SD = 662.046), and further from period two to period three (M = 119.707, SD = 664.504).

Table 3.

Exp. 1 Analysis of Variance for Heart Rate Variability

Source	Type III SS	df	MS	F	*p*	η_p^2
			Within-Subjects Effects			
P	12448026.977	2	6224013.489	38.362	.000	.375
P X D	165239.466	2	82619.733	.509	.602	.008
P X T	562811.696	2	281405.848	1.734	.181	.026
P X D X T	10082.214	2	5041.107	.031	.969	.000
S X P (D X T)	20767273.045	128	162244.321			
			Between-Subjects Effects			
D	29401.195	1	29401.195	.035	.852	.001
T	667269.331	1	667269.331	.795	.376	.012
D X T	2726065.690	1	2726065.690	3.247	.076	.048
S (D X T)	53737409.317	64	839647.021			

Note. D = (Task) Demands, T = Transition, P = (Time) Period.

Effort and goal regulation

Effort (TLX). The ANOVA for effort showed only a main effect of probe, see Table 4. The effect of probe was such that effort declined from probe one (M = 73.125, SD = 25.195) to probe three (M = 59.306, SD = 32.385).

Table 4.

Exp. 1 Analysis of Variance for Effort

Source	Type III SS	df	MS	F	*p*	η_p^2
			Within-Subjects Effects			
P	7003.009	2	3501.505	10.275	.000	.131
P X D	178.009	2	89.005	.261	.771	.004
P X T	2125.694	1.689	1258.318	3.119	.056	.044
P X D X T	64.583	2	32.292	.095	.910	.001
S X P (D X T)	46345.370	136	340.775			
			Between-Subjects Effects			
D	1896.296	1	1896.296	1.003	.320	.015
T	416.667	1	416.667	.220	.640	.003
D X T	7350.000	1	7350.000	3.889	.053	.054
S (D X T)	128501.852	68	1889.733			

Note. D = (Task) Demands, T = Transition, P = Probe.

Posttask questionnaire effort rating. For the posttask questionnaire effort ratings, paired one-tailed t tests were used for the pre- and posttransition scores of the HL and LH groups, respectively. Contrary to the predictions there were no significant changes between the pre- and posttransition effort scores for the HL group, $t(17) = 1.479$, $p = .079$, or the LH group, $t(17) = 0.353$, $p = .364$. In the HL group, two participants claimed on the posttask questionnaire to have experienced a LH transition instead. If these two participants are removed, the t-test for the HL group show the predicted significant decrease, $t(15) = 1.828$, $p = .006$.

Posttask questionnaire goal rating. Paired one-tailed t tests were used to compare the pre- and posttransition goal scores for the HL and LH groups to test the prediction that those in the HL condition should have increased their goals and those in the LH condition should have decreased their goals. As predicted, there was a significant decrease between the pre- and posttransition goal scores for the LH group, t(17) = 3.367, $p = .002$. However, there was no significant difference in the HL group, t(17) = 0.136, $p = .447$. In the HL group, two participants claimed on the posttask questionnaire to have experienced a LH transition instead. The result of the t-test for the HL group does not change if these participants are removed.

Performance

d-prime. The ANOVA for d' scores showed a significant main effect of task demands, a task demands by transition interaction, and a significant three-way interaction, see Table 5.

Table 5.

Exp. 1 Analysis of Variance for d'

Source	Type III SS	df	MS	F	*p*	η_p^2
			Within-Subjects Effects			
P	.161	2	.080	.135	.874	.002
P X D	35.569	2	17.784	29.818	.000	.305
P X T	.123	2	.062	.103	.902	.002
P X D X T	34.428	2	17.214	28.861	.000	.298
S X P (D X T)	81.116	136	0.596			
			Between-Subjects Effects			
D	52.177	1	52.177	21.384	.000	.239
T	.126	1	.126	.052	.821	.001
D X T	90.791	1	90.791	37.210	.000	.354
S (D X T)	165.918	68	2.440			

Note. D = (Task) Demands, T = Transition, P = (Time) Period.

The means for the four groups are shown in Figure 4. At period one there was a significant main effect of task demands, $F(1, 68) = 71.290, p < .001$, partial $\eta^2 = 0.512$, such that those who had low task demands had significantly higher d' scores (M = 3.748, SD = 1.442) than those who had high task demands (M = 1.618, SD = 0.405).

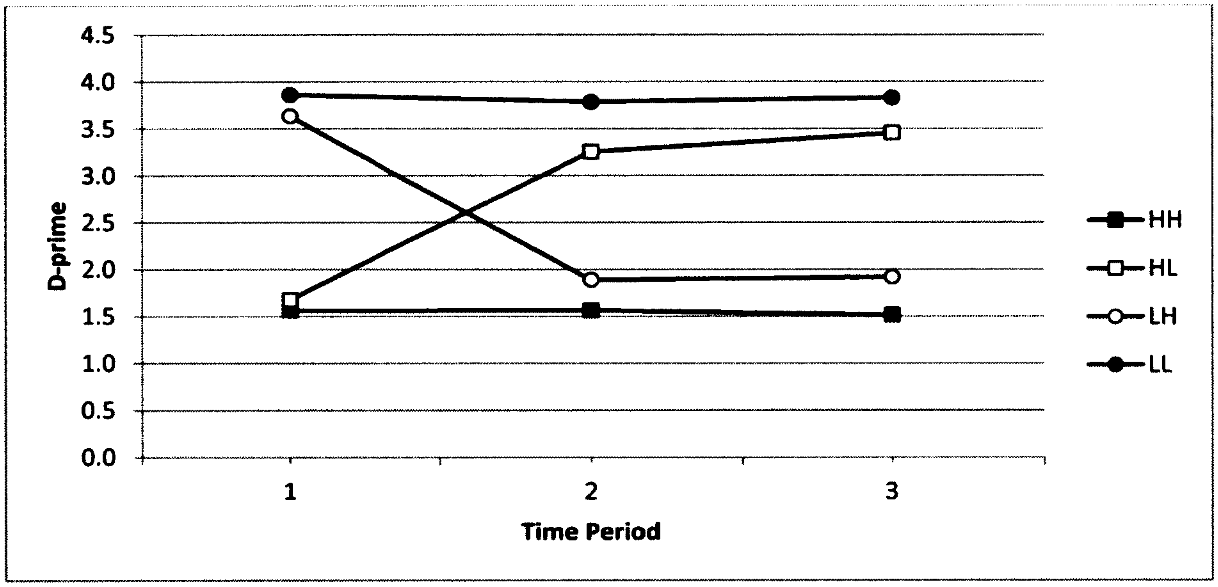

Figure 4. Exp. 1, d' scores across the three periods.

At period two there was a significant task demands by transition interaction, $F(1, 68) = 46.933$, $p < .001$, partial $\eta^2 = 0.408$, such that the LH group had significantly lower d' scores (M = 1.889, SD = 0.651) than the LL group (M = 3.786, SD = 1.534), but the HL group had significantly higher d' scores (M = 3.256, SD = 1.386) than the HH group (M = 1.564, SD = 0.492). Further, the LL group had higher d' scores than the HH group, and the HL group higher than the LH group.

The same pattern was observed for period three. A significant task demands by transition interaction, $F(1, 68) = 53.315$, $p < .001$, partial $\eta^2 = 0.439$, such that the LH group had significantly lower d' scores (M = 1.919, SD = 0.725) than the LL group (M = 3.831, SD = 1.594), but the HL group had significantly higher d' scores (M = 3.454, SD

= 1.237) than the HH group (M = 1.515, SD = 0.642). Further, the LL group had higher d' scores than the HH group, and the HL group higher than the LH group.

Repeated measures ANOVAs on d' over the three periods revealed no significant changes over time for the HH or LL groups. For the HL group, however, there was a significant change over time, $F(2, 34) = 26.078$, $p < .001$, partial $\eta^2 = 0.605$, such that the d' score increased from period one (M = 1.675, SD = 0.347) to period two (M = 3.256, SD = 1.386). The LH group also showed a significant effect, $F(2, 34) = 54.470$, $p < .001$, partial $\eta^2 = 0.762$, such that the d' score decreased from period one (M = 3.635, SD = 1.365) to period two (M = 1.889, SD = 0.651).

C scores. The ANOVA for the C scores showed a significant main effect of time period, task demands, a task demands by transition interaction, a time period by task demands interaction, and a significant three-way interaction, see Table 6.

Table 6.

Exp. 1 Analysis of Variance for Criterion C

Source	Type III SS	df	MS	F	p	η_p^2
			Within-Subjects Effects			
P	.580	2	.290	4.127	.018	.057
P X D	6.616	2	3.308	47.071	.000	.409
P X T	.380	2	.190	2.702	.071	.038
P X D X T	6.348	2	3.174	45.160	.000	.399
S X P (D X T)	9.558	136	0.070			
			Between-Subjects Effects			
D	3.863	1	3.863	16.829	.000	.198
T	.275	1	.275	1.197	.278	.017
D X T	19.041	1	19.041	82.945	.000	.550
S (D X T)	15.610	68	0.230			

Note. D = (Task) Demands, T = Transition, P = (Time) Period.

The means for the four groups are shown in Figure 5. At period one there was a significant main effect of task demands, $F(1, 68) = 74.343, p < .001$, partial $\eta^2 = 0.522$, such that those who had low task demands had significantly lower C scores (M = 0.462, SD = 0.440) than those who had high task demands (M = 1.223, SD = 0.292).

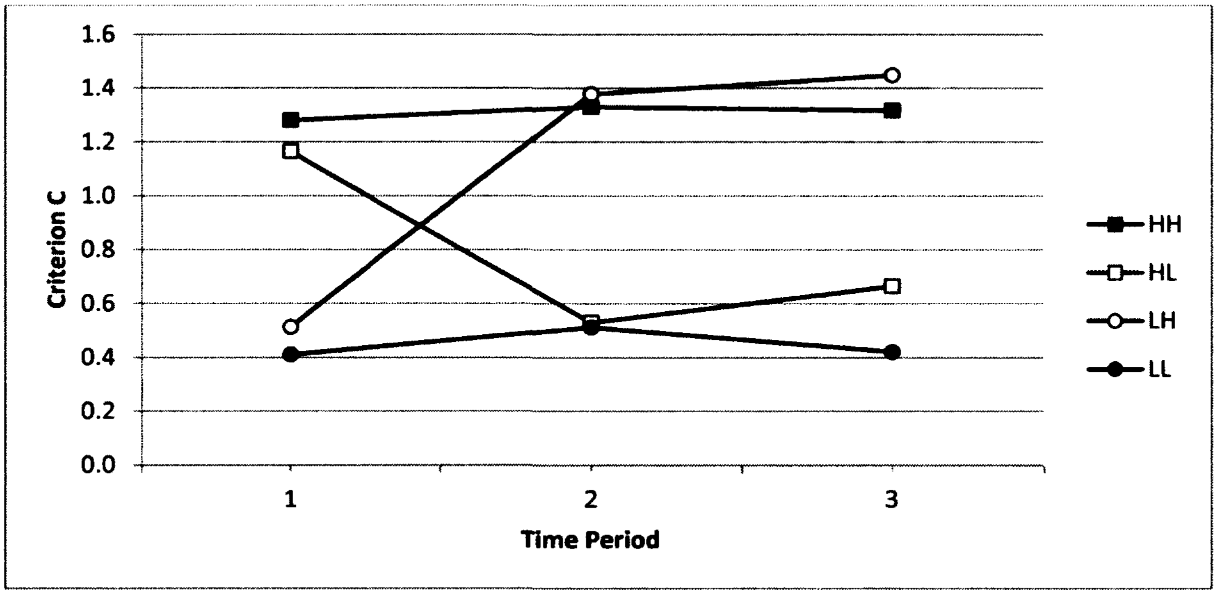

Figure 5. Exp. 1, criterion c-scores across the three periods.

At period two there was a significant task demands by transition interaction, $F(1, 68) = 118.055, p < .001$, partial $\eta^2 = 0.635$, such that the LH group had significantly higher C scores (M = 1.378, SD = 0.331) than the LL group (M = 0.512, SD = 0.301), but the HL group had significantly lower C scores (M = 0.529, SD = 0.383) than the HH group (M = 1.330, SD = 0.277).

At period three there was a significant main effect of transition, $F(1, 68) = 5.109$, $p = .027$, partial $\eta^2 = 0.070$, such that the transitioned groups had higher C scores (M = 1.057, SD = 0.534) than the nontransitioned groups (M = 0.869, SD = 0.566). There was also a task demands by transition interaction, $F(1, 68) = 102.138$, $p < .001$, partial η^2 = 0.600, such that the LH group had significantly higher C scores (M = 1.448, SD = 0.253) than the LL group (M = 0.421, SD = 0.304), but the HL group had significantly lower C scores (M = 0.665, SD = 0.445) than the HH group (M = 1.317, SD = 0.378). Further the LH group had higher C scores than the HL group.

A repeated measures ANOVA on C scores over the three time periods revealed no significant changes over time for the HH or LL groups. However, for the HL group there was a significant change over time, $F(2, 34) = 29.497$, $p < .001$, partial $\eta^2 = 0.634$, such that the C scores decreased from period one (M = 1.165, SD = 0.270) to period two (M = 0.529, SD = 0.383). For the LH group there was a significant effect, $F(2, 34) = 76.190$, $p < .001$, partial $\eta^2 = 0.818$, such that the C scores increased from period one (M = 0.513, SD = 0.425) to period two (M = 1.378, SD = 0.253).

Relation to effort. Pearson correlations were used to analyze the relationship between effort and performance. There were no significant correlations between task performance and effort in the HH, LL, or HL groups at probe one, two or three. For the LH group, there were no correlations at probe one or two. However, there was a significant correlation between the d' scores and the TLX effort rating at probe three, $r(18) = .553$, $p = .017$.

Workload

Mental demand (TLX). The ANOVA for the mental demand ratings showed a significant demand by transition interaction, a probe by demands interaction, and a significant three-way interaction, see Table 7.

Table 7.

Exp. 1 Analysis of Variance for Mental Demand

Source	Type III SS	df	MS	F	*p*	η_p^2
			Within-Subjects Effects			
P	902.778	2	451.389	2.731	.069	.039
P X D	5619.444	2	2809.722	16.999	.000	.200
P X T	978.704	2	489.352	2.961	.055	.042
P X D X T	4169.444	2	2084.722	12.612	.000	.156
S X P (D X T)	22479.630	136	165.291			
			Between-Subjects Effects			
D	4266.667	1	4266.667	2.367	.129	.034
T	312.963	1	312.963	.174	.678	.003
D X T	38400.000	1	38400.000	21.304	.000	.239
S (D X T)	122570.370	68	1802.505			

Note. D = (Task) Demands, T = Transition, P = Probe.

The means for the four groups are shown in Figure 6. There was a significant main effect of task demands, $F(1, 68) = 15.159, p < .001$, partial $\eta^2 = 0.182$, as well as a task demands by transition interaction for mental demand at probe one, $F(1, 68) = 5.950$, $p = .017$, partial $\eta^2 = 0.080$. The interaction was such that the LL group had lower mental demand ratings (M = 48.333, SD = 31.343) than the HH (M = 85.833, SD = 15.927), HL (M = 79.444, SD = 18.856), and LH (M = 70.833, SD = 30.546) groups.

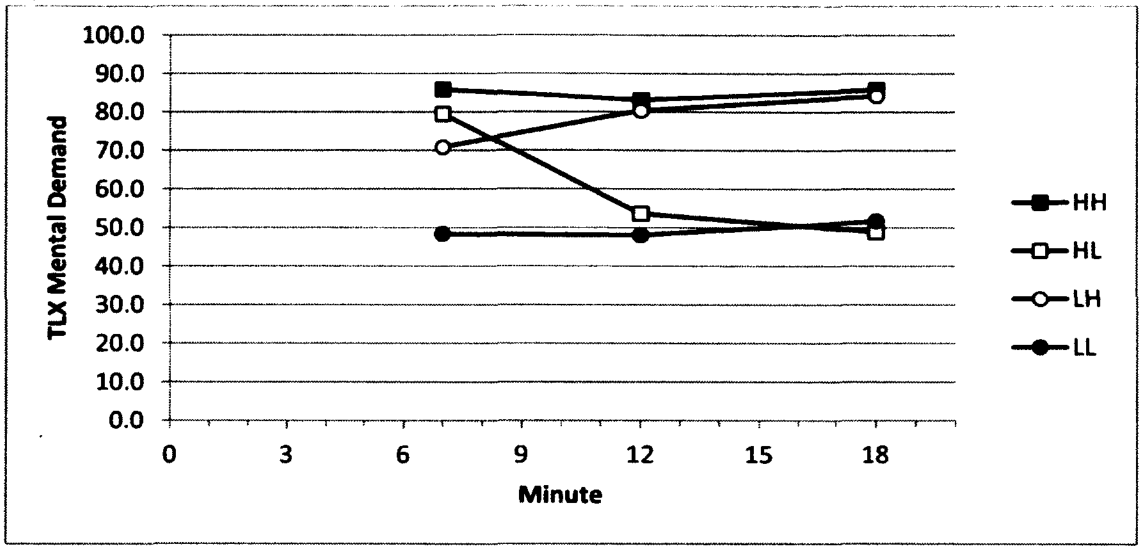

Figure 6. Exp. 1, mental demand ratings from the NASA TLX across the three probes.

There was a significant task demands by transition interaction effect at probe two, $F(1, 68) = 20.477$, $p < .001$, partial $\eta^2 = 0.231$, such that the HL group had significantly lower mental demand ratings (M = 53.611, SD = 32.890) than the HH group (83.056, SD = 19.714), but the LH group had significantly higher mental demand ratings (M = 80.278, SD = 23.731) than the LL group (M = 48.056, SD = 36.183). Further, the LL had significantly lower ratings than the HH group, and the HL group was lower than the LH group as well.

There was a significant task demands by transition interaction effect at probe three, $F(1, 68) = 32.574$, $p < .001$, partial $\eta^2 = 0.324$, such that the HL group had significantly lower mental demand ratings (M = 48.889, SD = 30.896) than the HH group (85.833, SD = 17.594), but the LH group had significantly higher mental demand ratings (M = 84.167, SD = 16.650) than the LL group (M = 51.667, SD = 33.519). Further, the LL had significantly lower ratings than the HH group, and the HL group was lower than the LH group as well.

Repeated measures ANOVAs on mental demand over the three probes for the HH and LL groups revealed no significant changes over time. However, the HL group exhibited a significant change over time, $F(2, 34) = 24.799, p < .001$, partial $\eta^2 = 0.593$, such that the mental demand ratings decreased from probe one (M = 79.444, SD = 18.856) to probe two (M = 53.611, SD = 32.890), but did not decrease significantly between probe two and probe three (M = 48.889, SD = 30.896). The LH group on the other hand showed a significant effect, $F(2, 34) = 4.445, p = .019$, partial $\eta^2 = 0.207$, such that the mental demand ratings increased from probe one (70.833, SD = 30.547) to probe three (84.167, SD = 16.650).

Temporal demand (TLX). The ANOVA on the temporal demand ratings showed a significant main effect of probe, a demands by transition interaction, a probe by demands interaction, and a significant three-way interaction, see Table 8.

Table 8.

Exp. 1 Analysis of Variance for Temporal Demand

Source	Type III SS	df	MS	F	p	η_p^2
			Within-Subjects Effects			
P	1631.120	2	815.560	4.454	.013	.061
P X D	6938.065	2	3469.032	18.947	.000	.218
P X T	1231.861	1.315	936.560	3.364	.058	.047
P X D X T	7576.028	2	3788.014	20.689	.000	.233
S X P (D X T)	24900.259	136	183.090			
			Between-Subjects Effects			
D	1048.963	1	1048.963	0.794	.376	.012
T	253.500	1	253.500	0.192	.663	.003
D X T	77976.000	1	77976.000	59.002	.000	.465
S (D X T)	89868.185	68	1321.591			

Note. D = (Task) Demands, T = Transition, P = Probe.

The means for the four groups are shown in Figure 7. There was a significant main effect of task demands, $F(1, 68) = 11.449, p = .001$, partial $\eta^2 = 0.144$, as well as a task demands by transition interaction for temporal demand at probe one, $F(1, 68) = 12.403, p = .001$, partial $\eta^2 = 0.154$. The interaction was such that the LL group had lower temporal demand ratings (M = 45.000, SD = 30.870) than the HH (M = 86.667, SD = 11.246), HL (M = 73.333, SD = 28.180), and LH (M = 74.167, SD = 27.346) groups.

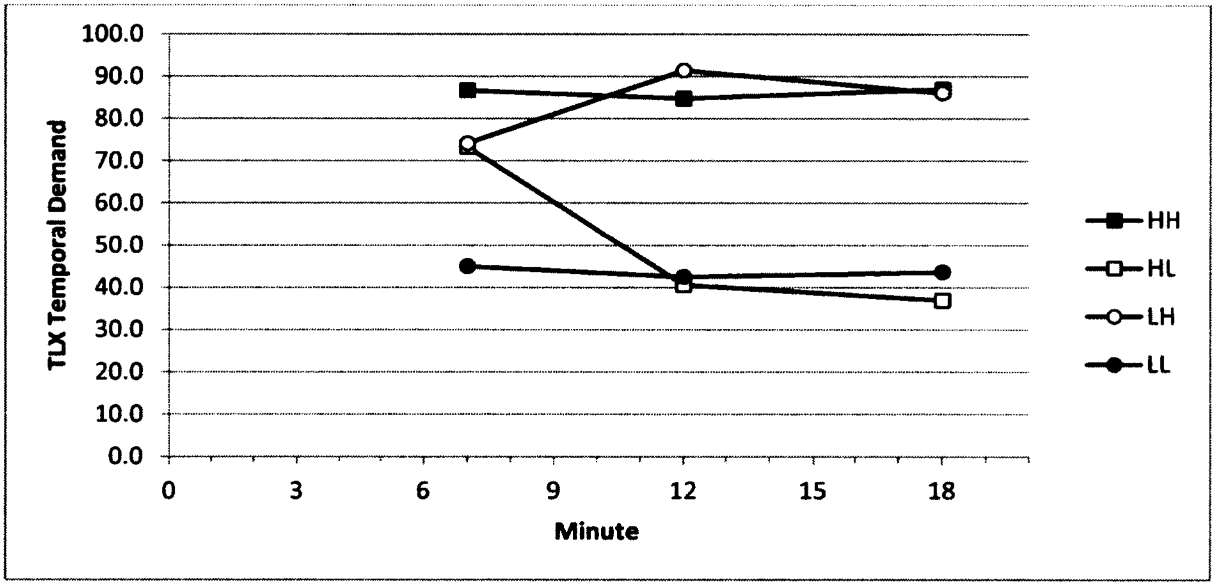

Figure 7. Exp. 1, temporal demand ratings from the NASA TLX across the three probes.

There was a significant task demands by transition interaction effect at probe two, $F(1, 68) = 78.930, p < .001$, partial $\eta^2 = 0.537$, such that the HL group had significantly lower temporal demand ratings (M = 40.556, SD = 27.110) than the HH group (84.389, SD = 16.039), but the LH group had significantly higher temporal demand ratings (M = 91.389, SD = 9.519) than the LL group (M = 42.500, SD = 29.865). Further, the LL has significantly lower ratings than the HH group, and the HL group was lower than the LH group as well.

There was a significant task demands by transition interaction effect at probe three, $F(1, 68) = 71.381, p < .001$, partial $\eta^2 = 0.512$, such that the HL group had significantly lower temporal demand ratings (M = 36.944, SD = 27.714) than the HH group (86.944, SD = 13.735), but the LH group had significantly higher temporal demand ratings (M = 86.056, SD = 14.412) than the LL group (M = 43.611, SD = 31.474). Further, the LL has significantly lower ratings than the HH group, and the HL group was lower than the LH group as well.

Repeated measures ANOVAs on temporal demand scores over the three probes for the HH and LL groups revealed no significant changes over time. There was however a significant change over time for the HL group, $F(2, 34) = 38.351, p < .001$, partial η^2 = 0.693, such that the temporal demand ratings decreased from probe one (M = 73.333, SD = 28.180) to probe two (M = 40.556, SD = 27.110), but did not decrease significantly between probe two and probe three (M = 36.944, SD = 27.714). For the LH group there was a significant effect, $F(2, 34) = 6.627, p = .004$, partial $\eta^2 = 0.280$, such that the temporal demand rating increased from probe one (74.167, SD = 27.346) to probe two (91.389, SD = 9.519) but did not change significantly between probe two and probe three (M = 86.056, SD = 14.412).

EXPERIMENT 1 DISCUSSION

The purpose of experiment 1 was to investigate the effects of a workload transition on stress and performance. Several theories have been suggested in the previous literature to explain conflicting findings on both task performance and stress. This experiment therefore included a range of predictions based primarily on transactional stress theory (Lazarus & Folkman, 1984), effort-regulation theory (Hockey, 1997), and mental resource theory (Kahneman, 1973).

Stress. According to transactional stress theory, stress is a mental state resulting from an individual's appraisal of his or her coping abilities contrasted with the demands imposed on the individual (Lazarus & Folkman, 1984). This appraisal is an ongoing process and changes in task demands should therefore be reflected in changes in the individual's stress state. Matthews et al. (2002) defined stress states by three different dimensions: distress, task engagement, and worry. Each dimension is associated with a different situational appraisal and a different mode of coping. Distress is primarily associated with appraisals of high workload and threats and emotion focused coping. Task engagement can be defined as effortful striving toward performance goals, and is associated with appraisals of high demands and high effort requirements, as well as task oriented coping. Worry is primarily associated with self-appraisal and emotion, and avoidance oriented coping. The dimensions of distress and task engagement have been previously shown to be affected by sudden workload transitions by Helton et al. (2004; 2008), but Ungar (2008) failed to replicate those findings. According to Helton et al. (2008), distress should increase following a transition in either direction. Task engagement, on the other hand, should follow the change in demands such that when demands increase so should the reported task engagement and when the demands decrease the reported task engagement should decrease as well. The final dimension of worry has not been sensitive to workload transitions in previous research.

Distress. Based on the work of Miceli and Castelfranchi (2005), Helton et al. (2008) theorized that the underlying reason behind a general transition-induced increase in distress would be increased uncertainty. A transition should increase a task operator's uncertainty about both current and future task load, which in turn would lead to increased distress. It was therefore predicted that the current experiment would replicate Helton et al.'s results and that a transition in either direction should increase distress (distress increase hypothesis). However, transactional stress theory also emphasizes that stress appraisal is a continuous process (Lazarus & Folkman, 1984). Therefore, over time the uncertainty should be reduced as the task operator is able to evaluate the new demands. Based on this theory it was predicted that over time the distress ratings should come to reflect the posttransition demand levels, which would replicate Ungar's (2008) results (continuous appraisal hypothesis).

Distress ratings were collected multiple times at given intervals because the current experiment focused on changes over time. It was shown that the transition had no effect on the distress ratings collected one minute posttransition. That is, the HL group was not different from the HH group, nor was the LH group different from the LL group. Over time, however, the ratings did change for the transition groups such that an increase in task demands led to increased distress, and a decrease in task demands to a decrease in distress. This change took place during the first six minutes posttransition and the transition groups remained stable thereafter for the remaining six minutes. These results do not support the distress increase hypothesis but they do support the continuous appraisal hypothesis.

One reason for the lack of a general distress increase in the current experiment could be that the transition did not increase uncertainty about current or future task demands. If the observer is accurate in their assessment of the new task demands the distress ratings should instead follow those new demands (Lazarus & Folkman, 1984). This is what Ungar (2008) found and also what the current experiment shows. Further research is needed on the relationship between workload transitions, uncertainty, and distress. Helton and colleagues' (2004; 2008) results indicate that the increase in distress is decoupled from the direction of the task demands. Thus, future research should manipulate both the direction and magnitude of the workload transition independent from the factors that influence the predictability and uncertainty of the same transition.

Task engagement and effort. Predictions for changes in task engagement and effort were based on Hockey's effort-regulation theory. Building on Kahneman's (1973) theory of mental resources, Hockey emphasized that individuals can regulate their resource investments (i.e., effort) voluntarily, even under stress and high workload. That is, in response to high workload an individual may choose to either invest additional effort in the task thereby maintaining their performance, or conserve effort and lower their performance goals. Based on this theory it was predicted that the transition groups would either change their effort to reflect the posttransition task demands (effort regulation hypothesis) or they would remain at the same effort level but change their goal states (goal regulation hypothesis).

Turning to the experimental results, there was no change in task engagement one minute after the transition. Similar to the dimension of distress, the HL group was not different from the HH group, and the LH group was not different from the LL group.

However, over time all groups except HL decreased their task engagement ratings. Those who experienced high task demands posttransition decreased their ratings more than those who experienced low task demands. The ratings of effort obtained from the NASA TLX showed no differences among the groups at any point during the experiment, and these effort ratings decreased over time across all groups. Further, the posttask questionnaire item relating to effort did not show an effect of the transition for either the HL or LH group. However, two participants in the HL group responded to the posttask questionnaire that they thought they noticed a LH transition. If these two participants are removed, the HL group showed a decrease in effort. Further, on the posttask questionnaire item relating to performance goals the LH group reported reduced goals in response to the transition.

Collectively, these findings do not support the effort regulation hypothesis, and support the goal regulation hypothesis for the LH group only. Although both the SSSQ measure of task engagement and TLX measure of effort showed changes over time none showed the predicted increase in effort in response to increased task demands. Rather, there was a general negative trend of decreased task engagement and effort. Along with this decline in effort, the LH group also decreased their goals. These results are in line with both Helton et al. (2008) and Ungar (2008), who found a general decline in task engagement over time as well. However, the current experiment failed to replicate Helton et al.'s finding of an increase in task engagement following an LH transition.

Although both effort-based and goal-based coping strategies are accommodated within Hockey's (1997) effort-regulation theory, the finding that the participants in the current experiment reduced their effort provokes further questions. Why would the individuals in Helton and colleagues' (2004; 2008) studies increase their effort in response to an increase in task demands when the individuals in the current experiment decreased their effort in response to a transition in the same direction? Helton et al. argued that the underlying reason for the increase in task engagement was due to an increase in the perceived challenge imposed by the task (Matthews & Falconer, 2000; 2002). The posttask questionnaire in the current experiment included items that specifically asked participants about how challenging they perceived the task to be overall, as well as how the transition changed their perception of the challenge imposed by the task. Overall, the HH and LH groups both rated the perceived challenge as high (4.444 and 4.167, respectively), as compared to the HL and LL groups' lower ratings (3.667 and 2.316, respectively). The LH group also indicated that the transition made the task more challenging (mean rating of 4.556). The HH and LH groups thus had the highest ratings of task-imposed challenge, yet these groups also had the lowest ratings of task engagement. The LL group had the lowest rating of challenge, yet the highest rating of task engagement. These findings are not compatible with the explanation that the perceived challenge would result in higher or lower task engagement. Instead, it is suggested that an alternative theory may be needed to explain the discrepancies among the current study and those of Ungar (2008) and Helton et al. (2004; 2008). The Motivational Intensity Theory (MIT) discussed by Brehm and Self (1989) will be explained further in the section on theoretical implications.

Physiological measure. Regarding the physiological measure, LF HRV power has been shown to be sensitive to task-oriented stress components, such as mental strain and effort (Aasman, Mulder, & Mulder, 1987; Fairclough & Roberts, 2011; Vicente, Thornton, & Moray, 1987). Predictions for the measures of LF HRV power in the current experiment were therefore based on Hockey's (1997) effort-regulation theory, such that an increase in task demands should decrease LF HRV power whereas a decrease in task demands should increase LF HRV power. However, these predicted physiological effects were not found in the current experiment. The LF HRV power increased over time across all groups, indicating that the participants adapted to, i.e. invested less effort into, the task over the course of the experiment.

As the physiological measures are sensitive to task-oriented stress and effort, the finding that LF HRV power increased over time is in agreement with the subjective reports of task engagement and effort. The subjective ratings of effort declined over time and the HRV data also suggests that effort was withdrawn over time. That is, it seems plausible that the predicted decrease in LF HRV power in response to an LH transition were absent because the participants did not engage in effortful coping. The MIT suggested in the section on task engagement also makes strong predictions for physiological, particularly cardiovascular, reactions to task demands and these predictions will be considered in the section on theoretical implications.

Workload. The hysteresis hypothesis, based on the short-term memory overload explanation suggested by Morgan and Hancock (2011), stated that the HL transition group should remain elevated on measures of stress and workload as compared to the LL control group. Morgan and Hancock suggested that this hysteresis effect is mediated by the short-term memory, such that a short-term memory overload will persist for a limited time even after the task demands have decreased. Thus, workload ratings obtained during a period of low task demands should be higher if there was a period of high demands immediately prior.

Support for this hypothesis can be found foremost in the subjective ratings of mental and temporal workload for the HL group. Consistent with the short-term memory explanation, the HL group retained a high workload rating one minute posttransition but decreased over time and were not different from the LL group five minutes later. The same pattern was also found for distress and task engagement. For the workload ratings, it should be noted that the LH group immediately increased their ratings within the first posttransition minute, possibly indicating that an immediate overload of a short-term memory buffer. This is in contrast with the measures of distress and task engagement, where the LH group did not change significantly from the LL control group within the same time frame. Although these results do not conclusively prove the short-term memory explanation of the hysteresis effect, they are in line with the predicted effects and also replicate the empirical findings of Morgan and Hancock in a different task setting.

Task performance. The primary theory that was used to predict performance effects was mental resource theory (Kahneman, 1973). According to this theory, performing a task depletes resources. Therefore, it was predicted that higher task demands would deplete more resources than low demands, and further participants who are transitioned from high to low demands should have fewer resources available compared to others operating under a constant level of low demands. In sum, the HL group should underperform compared to the LL group and the LH group should perform better than the HH group.

An alternative prediction, however, would appeal to Hockey's (1997) effort-regulation theory. Building on Kahneman's (1973) theory of mental resources, Hockey emphasized that individuals can regulate their resources voluntarily, particularly under stress and high workload. That is, in response to high workload individuals may either invest additional effort into the task thereby maintaining their performance level, or conserve effort and be willing to accept lower levels of performance. Thus, the effort-regulation theory predicts that performance would vary with the effort invested by the participants. Although effort was not directly manipulated in the current experiment the participants were asked to subjectively rate their effort in three ways. First, the SSSQ contains several items that combine to the factor of task engagement, which is a measure of effortful striving towards performance goals. Second, the NASA TLX contains a single item that asks participants directly to rate their effort from low to high. Finally, to assess the impact of the transition on effort the posttask questionnaire asked the participants to rate their effort *before* and *after* the transition.

In the current experiment, performance was measured by perceptual sensitivity and decision bias. It was found that the low task demand groups (LL, LH) showed higher perceptual sensitivity and a more conservative decision criterion prior to the transition compared to the high task demand groups (HH, HL). Posttransition, the perceptual sensitivity increased for those transitioned to lower demands and decreased for those transitioned to higher demands. Transitioning task demands also affected the participants' decision criterion such that they adapted a more conservative decision criterion in response to lower demands and more liberal criterion in response to higher demands. Although the perceptual sensitivity of the HL group remained below the LL group and the sensitivity of the LH group remained above the HH group, as predicted by mental resource theory, the transitioned groups did not differ significantly from their respective nontransitioned control groups. Thus, the mental resource hypothesis was not supported.

Furthermore, no reliable relationship was found between any measure of effort (task engagement, TLX effort ratings) and performance (d' and C). The correlation analyses were carried out on each group individually to control for the current and past task demands unique to each group. The only correlation within any of the groups between the performance measures and the effort measures was for the LH group in for the last period of task performance, where there was a correlation between d' and TLX effort ratings. Thus, the effort-performance relation hypothesis could not be supported.

Overall, the results indicate that perceptual sensitivity and decision criterion were driven more by the current task demands than either previously experienced demands or invested effort. These results are more in line with the findings of Helton et al. (2004; 2008) and Gluckman et al. (1993), who found transition groups and constant demand control groups performed comparably. By contrast, the present findings differ from those of Cox-Fuenzalida and her colleagues (Cox-Feunzalida et al., 2004; Cox-Fuenzalida et al., 2006), who have consistently found performance decrements following transitions. Certainly, the significant *increase* in perceptual sensitivity in response to a transition from high to low demands is directly counter to the claim of a general, transition-induced performance decrement.

There are some potential explanations as to why the predicted performance effects could not be detected in the current experiment. The mental resource hypothesis is based on the notion that individuals should use up more resources under high rather than low task demands. However, as Hockey's (1997) effort-regulation theory posits, the individual may instead opt to conserve their resources, and accept a lower level of performance. If fewer mental resources were spent, overall, than expected for the high task demand condition, it should lead to smaller or no differences between the transition groups and the constant demand groups in terms of resource depletion. That would lead to a small effect that might not be detectable within the context of the current experiment. This would also be indicated by lower subjective reports of effort, which is also what was found.

Theoretical implications

Motivational Intensity Theory. The MIT is based on an expectancy-value model, where the value and need of the outcome and the perceived probability that proper behavior will lead to the outcome are the determinants of *potential* motivation. This potential motivation determines the effort invested in outcome-oriented behavior, which is referred to as the *actual* motivation. High effort investment occurs when the task demands are high but within the individual's capabilities and also justified by the value of the outcome. When the demands exceed the individual's capabilities or outweigh the value of the outcome, the individual may not mobilize effortful behavior (Brehm & Self, 1989). Physiological indices of effort have been shown to increase with the difficulty of a task up until the task is perceived as impossible, at which point they instead show no effect or approach the levels exhibited by low difficulty control groups (Elliott, 1969; Ewing & Fairclough, 2010; Light & Obrist, 1983; Obrist et al., 1978; Wright et al., 1986). Studies have also found that subjective reports of effort, including the DSSQ dimension of task engagement, follow this pattern (Ewing & Fairclough, 2010; Wright et al., 1988).

In light of this theory, it is possible that the high task demands used in the current experiment exceeded what most participants considered possible, resulting in the observed decline in task engagement and effort. Further support for this explanation comes from the participants' rating of their goal level. Previous research based on MIT has shown that subjective goal attractiveness ratings increase with task demands up to a point where the task demands are deemed impossible, at which point the goal attractiveness ratings drop (Biner, 1987; Roberson, 1985; Wright et al., 1984). In the current experiment, those who were transitioned to higher task demands reported on the posttask questionnaire that they lowered their goals in response. The lower goal level in the current experiment may be a reflection of a decrease in goal attractiveness in response to perceived impossible demands.

The MIT may also explain the physiological results in the current experiment. It is possible that no physiological effects were found due to a withdrawal of effort and task engagement in response to excessively high task demands. The MIT predicts that there should be an increasing physiological response given higher task demands up until a point when the participant instead withdraws effort resulting in a lack of physiological effects. This relationship has been found using multiple physiological measures, including cardiovascular metrics such as heart rate, blood pressure, and heart rate variability (Elliott, 1969; Ewing & Fairclough, 2010; Light & Obrist, 1983; Obrist et al., 1978; Wright, 1996; Wright et al., 1986). The subjective and physiological indices in the current experiment support the explanation that the high task demands were so excessively high that the participants withdrew their effort.

Summary. The current experiment did not find the predicted stress effects in terms of immediate posttransition distress or task engagement changes. Contrary to the results of Helton et al. (2004; 2008) there was no general increase in distress following a transition, nor did task engagement follow the direction of the transition. Instead, the results showed a general decline in task engagement, and that distress followed the direction of the transition. The physiological measure of LF HRV power also indicated that the participants reduced their effort over time. These results are more in line with Ungar (2008) than Helton et al. (2004; 2008). The results also showed partial support for the continuous appraisal hypothesis which stated that the transition groups should approach the control groups over time. Further, the current experiment found reduced performance goals in response to the LH transition as predicted by the effort-regulation theory.

The MIT may be the most useful theory to explain the current results and guide future research in terms of task engagement, effort, subjective performance goals, and physiological measures. Although this theory has previously been used with only static load conditions, some predictions can be made concerning how certain changes in the experimental procedure would impact the results. First, a lower level of high task demand (e.g., 60 instead of 120 events per minute) should induce increased task engagement and effort following an LH transition, not a reduction as observed in the current experiment. This is because a smaller magnitude LH transition is more likely to be evaluated as "achievable" rather than the extremely difficult or "impossible" level in the current experiment, leading to increased effort. An HL shift should still yield a reduction in task engagement and effort, based on a simple energy conservation principle. The increase in effort should be evident in subjective measures of task engagement and effort, as well as physiological measures of HRV, which has been shown to be sensitive to task demand levels (Ewing & Fairclough, 2010). Second, added incentives should promote higher effort levels, compared to no incentive, for a moderately difficult workload transition (e.g., 30 to 60) but not for an extreme transition such as the one used in the current experiment. Added incentives should also be reflected in subjective estimates of effort and task engagement as well as physiological measures of HR, which has been shown to be sensitive to task incentives (Ewing & Fairclough, 2010).

As a first step, the prediction based on MIT that a smaller magnitude transition will yield increased effort will be tested in a second experiment. This second experiment will be a replication of the first experiment but will use 60 rather than 120 events per minute as the high task demand condition. If the prediction holds, this second experiment would also replicate Helton et al.'s (2004; 2008) findings that an LH transition increases task engagement. Given the predicted changes in effort regulation there may also be an effect on the performance of the transition groups. Increased effort investment by the LH transition group may improve their performance as compared to a static high control group. However, it should be noted that no stable relationship between performance and effort was established in the first experiment and an increase in effort may not necessarily be reflected in performance.

The general finding that participants adjust to the new task demand levels over time, as reflected in subjective ratings of stress and workload, should be replicated in the second experiment. It is unlikely that using a lower level of high demand will bring about the increased uncertainty that is likely necessary for a general increase in distress following the transition. Rather, as predicted by transactional stress theory (Lazarus & Folkman, 1984), distress should follow the task demands as in the first experiment.

CHAPTER IV

EXPERIMENT 2

A second experiment was conducted to explore the effect of transition magnitude on stress and effort-focused coping. The first experiment showed only a general decrease in effort over time, rather than an effort increase in response to an LH transition as found by Helton et al. (2004; 2008). The lack of effort increase may be due to the fact that the high task demand level in the first experiment was so high that it was perceived as unattainable by most participants. The MIT (Brehm & Self, 1989; Wright & Brehm, 1989; Wright & Dill, 1993, Wright & Dismukes, 1995) states that a task perceived as too challenging in relation to the rewards of successful performance will lead to reduced effort. Although Ungar (2008) and Ungar et al. (2005) found that the absolute level of task difficulty was an important factor in workload transitions, they did not explore this idea any further. The second experiment was conducted to examine if a transition of smaller magnitude would result in a qualitatively different stress and effort-regulation response as compared to a large magnitude transition used in the first experiment.

HYPOTHESES

Overall, the second experiment should replicate the general findings of the first experiment. The continuous appraisal hypothesis should be supported in the second experiment as in the first, because the smaller magnitude transition should not affect the stress appraisal process. The hysteresis hypothesis should also be supported if the difference in high and low task demands in the second experiment is still sufficiently large to create different loads on short-term memory and distinctly different workload ratings. In contrast with the first experiment, the effort regulation hypothesis should be supported in the second experiment as the smaller magnitude LH transition should encourage greater effort investment than the large magnitude transition in experiment 1. This hypothesis should be supported by both subjective and physiological measures. The mental resource hypothesis and the effort-performance relation hypothesis were not supported in the first experiment, but may be supported in the second if the predicted change in effort is shown. That is, if the lower magnitude transition results in greater effort by the LH group they may also perform better than the HH group and thereby support the mental resource hypothesis. This should also establish a clear connection between effort and performance in the current task, supporting the effort-performance relationship hypothesis. The distress increase hypothesis was not supported by the first experiment, potentially because the transition did not increase uncertainty. It is therefore unlikely that the moderate transition used in the current experiment will result in greater distress for the transition groups.

METHOD

Participants. Seventy-eight participants were recruited from the same participant pool as Experiment 1. Six participants were removed prior to analysis due to either incomplete data sets (three participants) or failure to follow the instructions (three participants). Thus, the final sample size was the same as in Experiment 1 with a total of 72 participants in four groups of 18. The sample consisted of 25 male and 47 female students, all 18 years or older with a mean age of 21.63 years (SD = 6.37). An attempt was made to balance sex across the experimental conditions, with males comprising 28%

to 39% of all groups. All participants had normal or corrected-to-normal vision and none was allergic to latex or gels.

Procedure. The same task and experimental procedure was used as in Experiment 1. The only difference was that the high task demand level was set to 60 rather than 120 events per minute. The task performance measures, subjective stress and workload measures, and physiological measures were also identical to those in the first experiment.

The posttask questionnaire was also the same as in the first experiment, with one addition. If the participants stated that they experienced a transition they were also asked, at the end of the questionnaire, to indicate when during the experiment they experienced the transition. This addition was motivated by the indications from the first experiment that a fair number of the participants in the control conditions experienced a transition when none was present (see Appendix C). Patterns of these claimed transitions may be made clearer by asking the participants to indicate both the type of the transition and when during the experiment it occurred.

EXPERIMENT 2 RESULTS

Data treatment. The data treatment was identical to that of experiment 1 in terms of outlier and assumptions testing. The SSSQ pretask differences were also assessed across the four groups in the same way as for experiment 1 with no differences for task engagement (all $p > .307$), distress (all $p > .119$), or worry (all $p > .309$). Further, there were no differences among the groups in resting HRV ($p > .281$). These variables where converted to change scores by subtracting the individual pretask baseline from each subsequent score. Signal detection measures of d' and C were calculated across hit rates and false alarm rates across the same three time periods. The general analytical approach was the same as in experiment 1.

Comparison to experiment 1. Given that the LL groups in experiment 1 and experiment 2 received the exact same treatment the two groups were compared across the variables of interest to test for differences between the two samples. Separate 2 (experiment one or two) by 3 (probe: one, two, or three) ANOVAs were used. Any significant main effects of experiment or experiment by probe interactions were noted as indicating a difference between the two samples. There were no significant differences for the SSSQ dimensions of task engagement ($p > .134$), or worry ($p > .447$); TLX ratings of mental demands ($p > .258$), temporal demands ($p > .158$), effort ($p > .404$), subjective performance ($p > .390$), or frustration ($p > .566$); or performance measures of d' ($p > .416$), criterion c ($p > .244$), or response time ($p > .444$). There was however a significant interaction between experiment and probe for distress, $F(2, 34) = 6.241, p = .003$, partial $\eta^2 = 0.155$, such that the LL group from the second experiment had significantly higher distress at probe three (M = 2.252, SD = 2.418) compared to the LL group from the first experiment (M = 0.616, SD = 0.978). Independent sample t tests were also used to test for pretask differences between the two samples. No significant differences were found between task engagement, $t(34) = 0.936, p = .356$, distress, $t(34) = 0.608, p = .608$, or worry, $t(34) = 0.751, p = .458$.

Posttask questionnaire data. One-tailed t-tests on the posttask questionnaire data showed, as expected, that the HH group rated the task as harder, more exhausting, more demanding, and more stressful than the LL group (all $p < .040$). The constant control groups also agreed more with the statement that the task demands remained consistent throughout the experiment than the transition groups, $t(70) = 3.169, p = .002$. The complete data set from the posttask questionnaires can be found in Appendix D.

Stress

Distress. The ANOVA for distress showed a significant main effect of probe, a probe by task demands interaction, and a probe by transition interaction, see Table 9.

Table 9.

Exp. 2 Analysis of Variance for Distress

Source	Type III SS	df	MS	F	*p*	η_p^2
			Within-Subjects Effects			
P	19.958	2	9.979	10.462	.000	.133
P X D	19.380	2	9.690	10.159	.000	.130
P X T	11.191	2	5.596	5.867	.004	.079
P X D X T	2.164	2	1.082	1.135	.325	.016
S X P (D X T)	129.721	136	0.954			
			Between-Subjects Effects			
D	.382	1	.382	.054	.818	.001
T	13.787	1	13.787	1.934	.169	.028
D X T	.043	1	.043	.006	.938	.000
S (D X T)	484.831	68	7.130			

Note. D = (Task) Demands, T = Transition, P = Probe.

The means for the four groups are shown in Figure 8. The probe by task demands interaction was such that the groups that received high task demands had higher ratings of distress at probe one (M = 1.445, SD = 1.402) than those who received low task demands (M = 0.400, SD = 1.434) but there were no significant differences at probes two or three. The effect of probe by transition interaction on the other hand was such that the groups that experienced a transition did not significantly increase their distress rating over time whereas the groups that did not experience a transition did increase their distress from probe one (M = 0.7070 SD = 0.277) to probe three (M = 1.889 SD = 0.360).

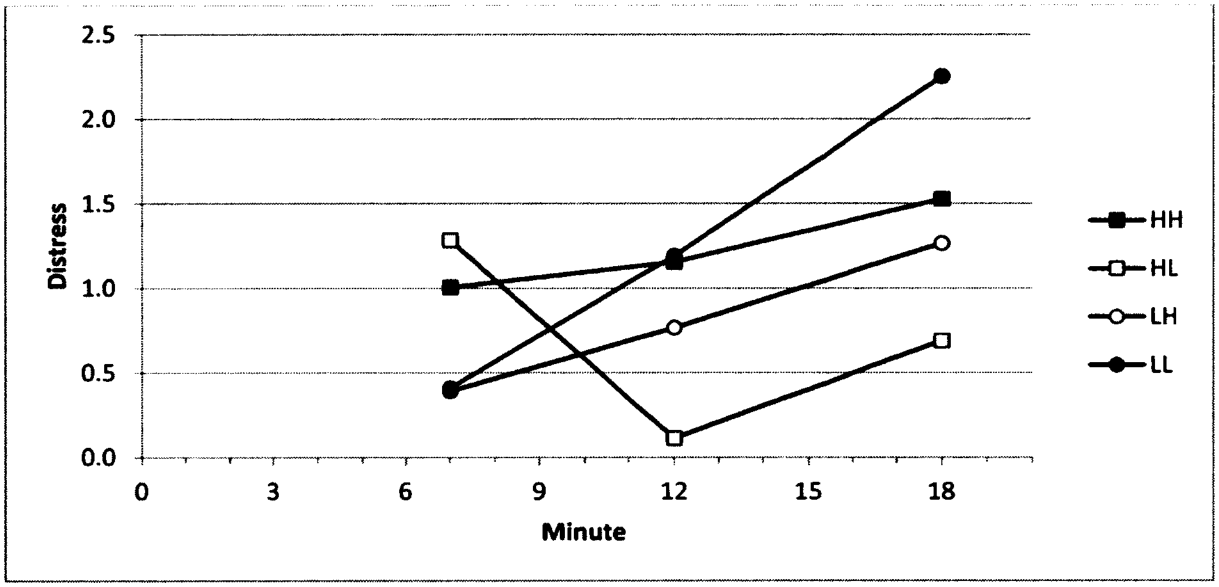

Figure 8. Exp. 2, standardized distress change scores across the three probes.

Task engagement. The ANOVA for task engagement showed main effects of task demands and a main effect of probe, see Table 10.

The means for the four groups are shown in Figure 9. The effect of task demands was such that the groups that received low task demands for the first six minutes had higher task engagement than those who received high task demands. The effect of probe was such that task engagement overall declined from probe one (M = 0.307, SD = 0.764) to probe two (M = 0.100, SD = 0.965), and then further from probe two to probe three (M = -0.472, SD = 1.100).

Table 10.

Exp. 2 Analysis of Variance for Task Engagement

Source	Type III SS	df	MS	F	*p*	η_p^2
			Within-Subjects Effects			
P	23.471	2	11.735	43.146	.000	.388
P X D	.162	2	.081	.299	.742	.004
P X T	.377	2	.188	.693	.502	.010
P X D X T	.129	2	.064	.237	.790	.003
S X P (D X T)	36.991	136	0.272			
			Between-Subjects Effects			
D	10.097	1	10.097	4.735	.033	.065
T	.289	1	.289	.136	.714	.002
D X T	.440	1	.440	.206	.651	.003
S (D X T)	144.995	68	2.132			

Note. D = (Task) Demands, T = Transition, P = Probe.

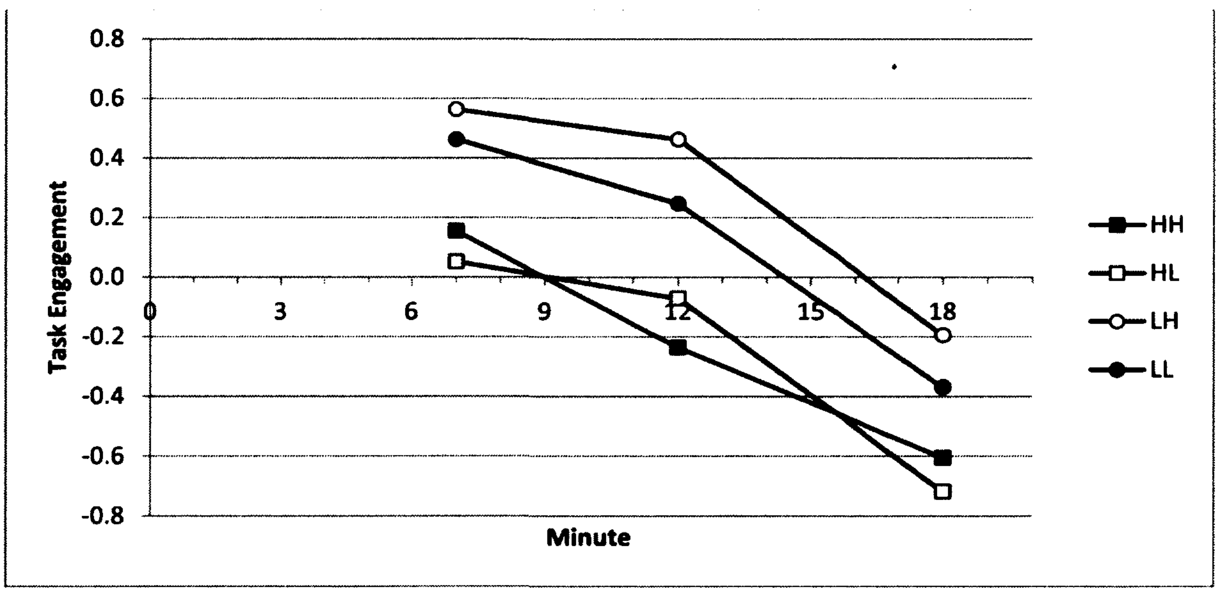

Figure 9. Exp. 2, standardized task engagement change scores across the three probes.

Heart rate variability. The ANOVA for HRV showed a significant main effect of period, a period by task demands interaction, and a three-way interaction between period, task demands, and transition, see Table 11. There were no significant effects at periods one or two, but there was a significant task demands by transition interaction at probe three, $F(1, 68) = 4.544, p = .037$, partial $\eta^2 = 0.063$. An uncorrected follow-up test showed that the LH group had significantly lower HRV change scores (M = -455.853, SD = 849.390) than the LL group (M = 267.667, SD = 860.942) but this and all other differences were not significant after applying post hoc corrections.

Table 11.

Exp. 2 Analysis of Variance for Heart Rate Variability

Source	Type III SS	df	MS	F	*p*	η_p^2
			Within-Subjects Effects			
P	11373529.899	2	5686764.949	19.444	.000	.222
P X D	2757939.214	2	1378969.607	4.715	.010	.065
P X T	107750.194	2	53875.097	.184	.832	.003
P X D X T	3773571.124	2	1886785.562	6.451	.002	.087
S X P (D X T)	39775110.191	136	292464.046			
			Between-Subjects Effects			
D	54302.468	1	54302.468	.030	.863	.000
T	4649616.436	1	4649616.436	2.564	.114	.036
D X T	1145240.724	1	1145240.724	.631	.430	.009
S (D X T)	123335304.112	68	1813754.472			

Note. D = (Task) Demands, T = Transition, P = (Time) Period.

The repeated measures ANOVA on HRV over the three time periods for the HH group revealed a significant change over time, $F(2, 34) = 6.688, p = .004$, partial $\eta^2 = 0.282$, such that the mean score increased from period one (M = -562.159, SD = 675.502) to period two (M = -58.669, SD = 757.668) but did not increase further to period three (M = -168.278, SD = 565.152). For the LL group there was a similar significant effect, $F(2, 34) = 4.672, p = .016$, partial $\eta^2 = 0.216$, such that the mean score increased from period one (M = -370.206, SD = 1032.181) to period three (M = 267.667, SD = 860.942). The HL group showed a significant change over time, $F(2, 34) = 11.785, p < .001$, partial $\eta^2 = 0.409$, such that the mean score increased from period one (M = -1024.441, SD = 920.238) to period two (M = -299.855, SD = 925.367) but did not increase further to period three (M = 91.776, SD = 1431.716). However, there was no significant effect for the LH group, $F(2, 34) = 0.891, p = .419$, partial $\eta^2 = 0.050$.

Effort and goal regulation

Effort (TLX). The ANOVA for effort showed a main effect of probe, and a task demands by transition interaction, see Table 12.

Table 12.

Exp. 2 Analysis of Variance for Effort

Source	Type III SS	df	MS	F	*p*	η_p^2
			Within-Subjects Effects			
P	11634.954	2	5817.477	17.527	.000	.205
P X D	918.750	2	459.375	1.384	.254	.020
P X T	41.898	2	20.949	.063	.939	.001
P X D X T	1514.583	2	757.292	2.282	.106	.032
S X P (D X T)	45139.815	136	331.910			
			Between-Subjects Effects			
D	1276.042	1	1276.042	.848	.361	.012
T	402.894	1	402.894	.268	.607	.004
D X T	12376.042	1	12376.042	8.220	.006	.108
S (D X T)	102378.241	68	1505.562			

Note. D = (Task) Demands, T = Transition, P = Probe.

The effect of probe was such that effort declined from probe two (M = 66.389, SD = 28.012) to probe three (M = 54.306, SD = 30.996). The means for the four groups are shown in Figure 10. The task demand by transition interaction was such that the LH group had higher overall effort level (M = 75.556, SD = 17.638) compared to the HL group (M = 55.556, SD = 23.935).

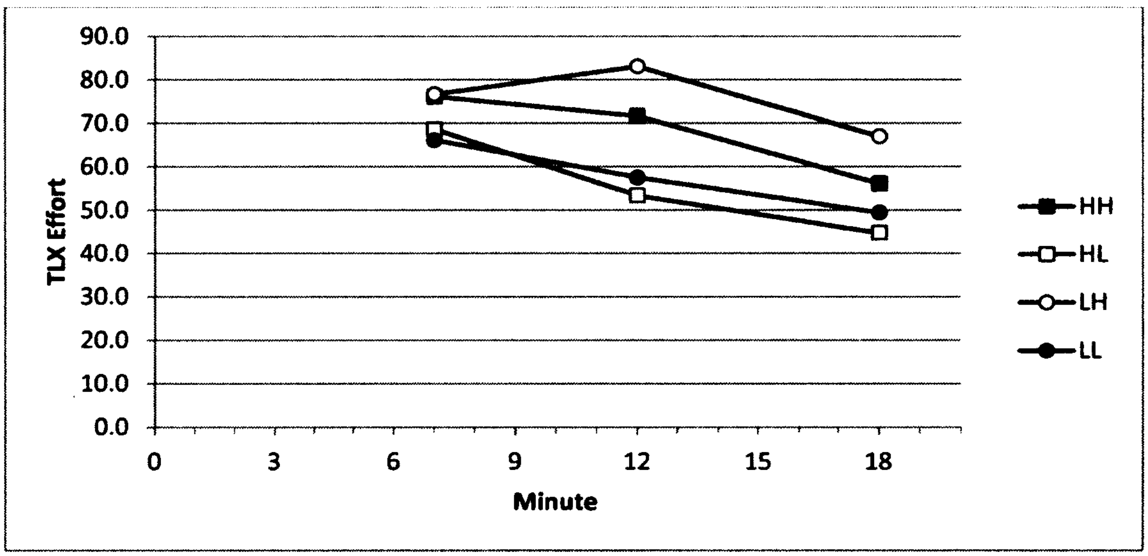

Figure 10. Exp. 2, NASA TLX effort ratings across the three probes.

Posttask questionnaire effort rating. A paired one-tailed t-test was used to compare the pre- and posttransition effort scores from the posttask questionnaire for the HL and LH groups, respectively. As predicted, the HL group significantly decreased their effort, t(17) = 2.315, p = .017, whereas the LH group significantly increased their effort, t(17) = 2.803, p = .006. Figure 11 compares the effort ratings of the HL and LH groups across the two experiments. In the LH group, one participant claimed to have experienced a HL transition instead, and in the HL group six participants claimed to have experienced a LH transition instead. The results of the t-tests do not change if these participants are removed.

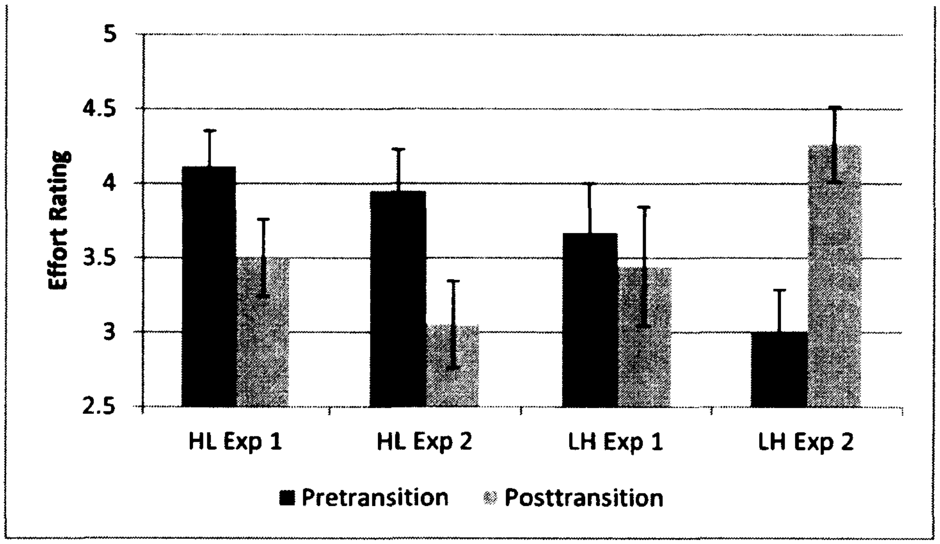

Figure 11. Exp. 2, posttask questionnaire effort ratings across experiments one and two for the HL and LH groups.

Posttask questionnaire goal rating. A paired one-tailed t test for pre- and posttransition goal scores for the HL and LH group were used to test the prediction that HL should have increased posttransition goals and LH should have decreased posttransition goals. However, the results did not reach significance for either the HL group, t(17) = 0.136, p = .378, or the LH group, t(17) = 1.728, p = .051. Figure 12 shows the goal ratings for the HL and LH groups in experiment one and two. In the LH group, one participant claimed to have experienced a HL transition instead, and in the HL group six participants claimed to have experienced a LH transition instead. The result of the t-test for the HL group does not change if these participants are removed, but the LH group does show a significant decrease in posttransition goals, t(16) = 1.953, $p = .034$ with these participants removed.

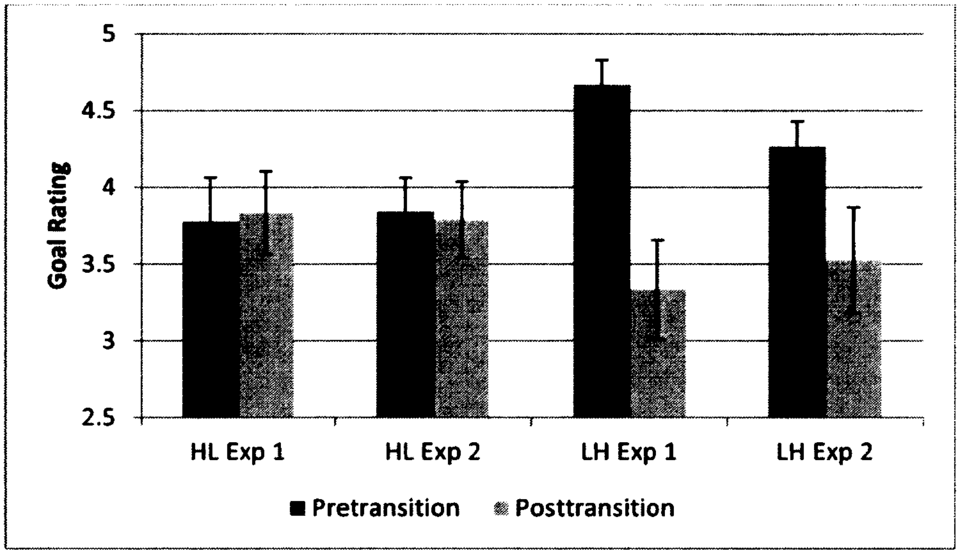

Figure 12. Exp. 2, posttask questionnaire performance goal ratings across experiments one and two for the HL and LH groups.

Performance

d-prime. The ANOVA for d' scores showed a significant main effect of task demands, a task demands by transition interaction, a probe by demands interaction, and a significant three-way interaction, see Table 13.

The means for the four groups are shown in Figure 13. At period one there was a significant main effect of task demands, $F(1, 68) = 26.284$, $p < .001$, partial $\eta^2 = 0.279$, such that those who had low task demands had significantly higher d' scores (M = 3.934, SD = 1.217) than those who had high task demands (M = 2.494, SD = 1.166).

At period two there was a significant task demands by transition interaction, $F(1, 68) = 20.284$, $p < .001$, partial $\eta^2 = 0.230$, such that the LH group had significantly lower d' scores (M = 2.961, SD = 1.422) than the LL group (M = 4.387, SD = 1.490), but the HL group had significantly higher d' scores (M = 3.970, SD = 1.401) than the HH group (M = 2.708, SD = 1.169). Further, the LL group had higher d' scores than the HH group.

Table 13.

Exp. 2 Analysis of Variance for d'

Source	Type III SS	df	MS	F	*p*	η_p^2
			Within-Subjects Effects			
P	3.124	2	1.562	2.794	.065	.039
P X D	15.311	2	7.655	13.694	.000	.168
P X T	.034	2	.017	.030	.970	.000
P X D X T	8.461	2	4.231	7.568	.001	.100
S X P (D X T)	76.028	136	0.559			
			Between-Subjects Effects			
D	25.511	1	25.511	7.080	.010	.094
T	.396	1	.396	.110	.741	.002
D X T	37.211	1	37.211	10.328	.002	.132
S (D X T)	245.009	68	3.603			

Note. D = (Task) Demands, T = Transition, P = (Time) Period.

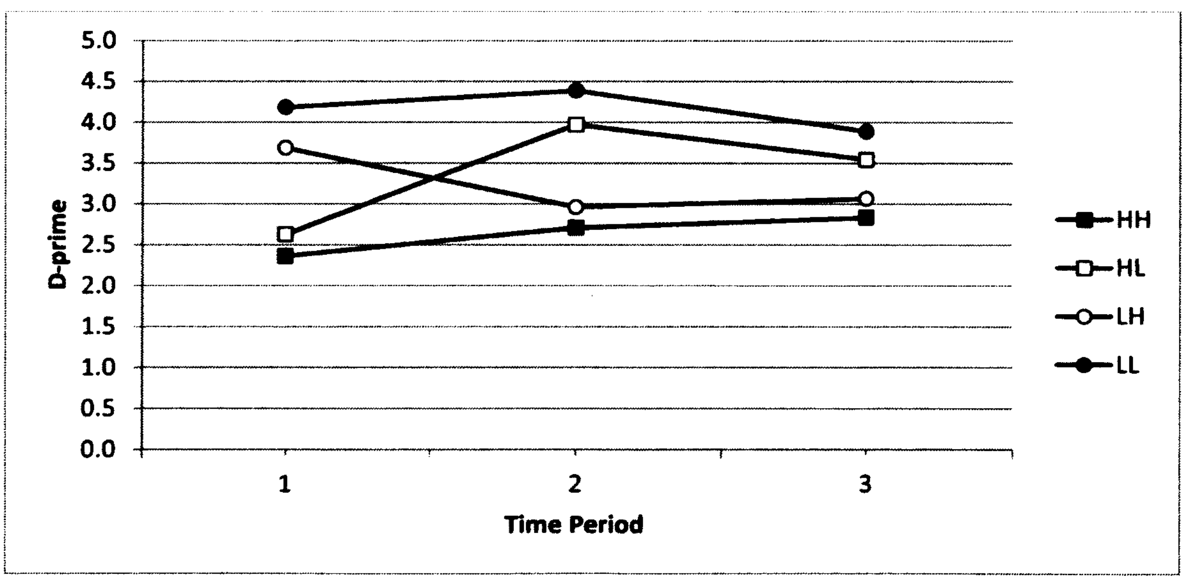

Figure 13. Exp. 2, d' scores across the three time periods.

At period three there was a significant task demands by transition interaction, $F(1, 68) = 6.211$, $p = .015$, partial $\eta^2 = 0.084$. An uncorrected follow-up test showed that the LL group had significantly higher d' scores (M = 3.887, SD = 1.374) than the HH group (M = 2.834, SD = 1.247) but this and all other differences were not significant after applying post hoc corrections.

Repeated measures ANOVAs on d' over the three periods revealed a significant changes over time for the HH group, $F(2, 34) = 5.272$, $p = .010$, partial $\eta^2 = 0.237$, such that the d' scores increased from time one (M = 2.362, SD = 0.953) to time three (M = 2.834, SD = 1.247). There was no significant effect over time for the LL group, $F(2, 34) = 1.349$, $p = .273$, partial $\eta^2 = 0.074$. For the HL group there was a significant change over time, $F(2, 34) = 10.608$, $p < .001$, partial $\eta^2 = 0.384$, such that the d' score increased from period one (M = 2.626, SD = 1.362) to period two (M = 3.970, SD = 1.401). The LH group also showed a significant effect, $F(2, 34) = 7.074$, $p = .003$, partial $\eta^2 = 0.294$, such that the d' score decreased from period one (M = 3.685, SD = 1.202) to period two (M = 2.961, SD = 0.929).

C scores. The ANOVA for the C scores showed a significant main effect of time period, a task demands by transition interaction, a time period by task demands interaction, and a significant three-way interaction, see Table 14.

The means for the four groups are shown in Figure 14. At period one there was a significant main effect of task demands, $F(1, 68) = 13.538$, $p < .001$, partial $\eta^2 = 0.166$, such that those who had low task demands had significantly lower C scores (M = 0.432, SD = 0.558) than those who had high task demands (M = 0.837, SD = 0.352).

Table 14.

Exp. 2 Analysis of Variance for Criterion C

Source	Type III SS	df	MS	F	*p*	η_p^2
			Within-Subjects Effects			
P	.589	2	.295	3.719	.027	.052
P X D	1.442	2	.721	9.095	.000	.118
P X T	.154	2	.077	.970	.382	.014
P X D X T	1.080	2	.540	6.814	.002	.091
S X P (D X T)	10.778	136	0.079			
			Between-Subjects Effects			
D	1.628	1	1.628	2.730	.103	.039
T	.769	1	.769	1.290	.260	.019
D X T	4.826	1	4.826	8.091	.006	.106
S (D X T)	40.553	68	0.596			

Note. D = (Task) Demands, T = Transition, P = (Time) Period.

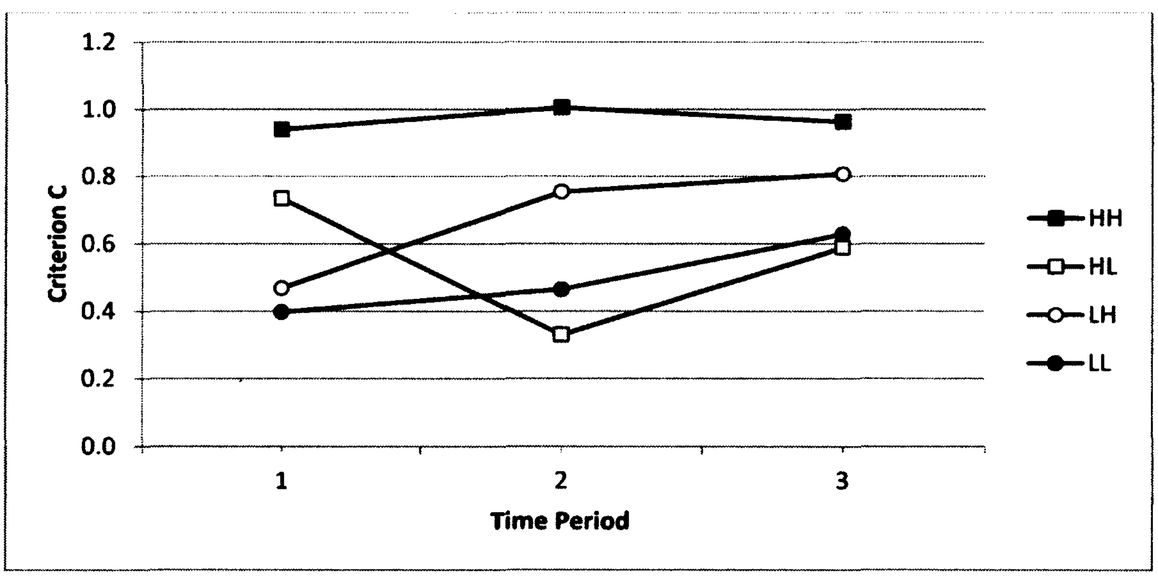

Figure 14. Exp. 2, criterion c scores across the three time periods.

At period two there was a significant task demands by transition interaction, $F(1, 68) = 15.367, p < .001$, partial $\eta^2 = 0.184$, such that the HL group had significantly lower C scores (M = 0.330, SD = 0.607) than the HH group (M = 1.005, SD = 0.393).

There was a significant task demands by transition interaction at period three, $F(1, 68) = 5.201, p = .026$, partial $\eta^2 = 0.071$. An uncorrected follow-up test showed that the HL group had significantly lower C scores (M = 1.887, SD = 0.763) than the HH group (M = 2.953, SD = 1.395) but this and all other differences were not significant after applying post hoc corrections.

A repeated measures ANOVA on C scores over the three time periods revealed no significant changes over time for the HH or LL groups. However, for the HL group there was a significant change over time, $F(2, 34) = 6.674, p = .004$, partial $\eta^2 = 0.282$, such that the C scores decreased from period one (M = 0.734, SD = 0.392) to period two (M = 0.330, SD = 0.607). For the LH group there was a significant effect, $F(2, 34) = 11.764, p < .001$, partial $\eta^2 = 0.409$, such that the C scores increased from period one (M = 0.468, SD = 0.518) to period two (M = 0.754, SD = 0.351).

Relation to effort. Pearson correlations were used to analyze the relationship between effort and performance. As in experiment 1 there were no significant correlations at any time point between effort and performance for the HL, HH, or LL groups. For the LH group, there were two noteworthy correlations at probe one, between d' and effort, $r(18) = -.521, p = .026$, and criterion C and effort, $r(18) = .558, p = .016$. At probe three the LH group also showed a significant correlation between d' and task engagement $r(18) = .474, p = .047$.

Workload

Mental demand (TLX). The ANOVA for the mental demand ratings showed a significant main effect of probe, a demand by transition interaction, a probe by demands interaction, and a significant three-way interaction, see

Table 15.

Table 15.

Exp. 2 Analysis of Variance for Mental Demand

Source	Type III SS	df	MS	F	*p*	η_p^2
			Within-Subjects Effects			
P	1453.009	2	726.505	3.066	.050	.043
P X D	4736.343	2	2368.171	9.994	.000	.128
P X T	102.083	2	51.042	.215	.806	.003
P X D X T	4430.787	2	2215.394	9.349	.000	.121
S X P (D X T)	32227.778	136	236.969			
			Between-Subjects Effects			
D	325.116	1	325.116	.198	.658	.003
T	126.042	1	126.042	.077	.783	.001
D X T	12527.894	1	12527.894	7.618	.007	.101
S (D X T)	111826.389	68	1644.506			

Note. D = (Task) Demands, T = Transition, P = Probe.

The means for the four groups are shown in Figure 15. There was a significant main effect of task demands, $F(1, 68) = 7.706, p = .007$, partial $\eta^2 = 0.102$ at probe one such that the groups that received low task demands had significantly lower mental demand ratings (M = 59.306, SD = 26.326) compared to the groups that received high task demands (M = 75.000, SD = 20.736).

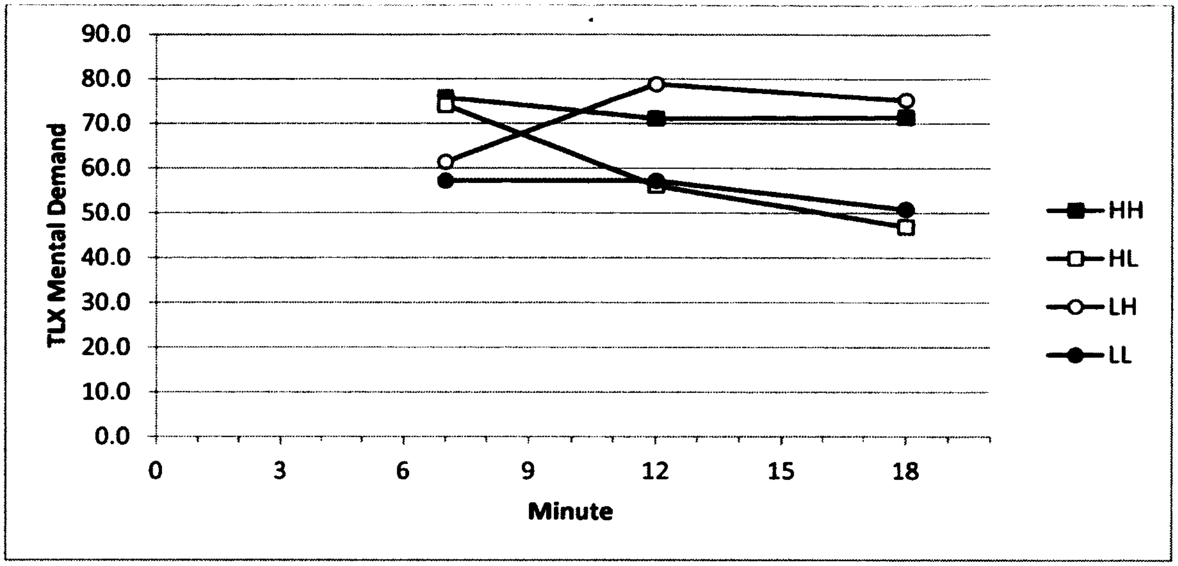

Figure 15. Exp. 2, NASA TLX mental demand ratings across the three probes.

There was a significant task demands by transition interaction effect at probe two, $F(1, 68) = 7.474, p = .008$, partial $\eta^2 = 0.099$. Uncorrected follow-up tests showed that the LH group had higher mental demand ratings (M = 78.889, SD = 23.674) than the LL group (M = 57.222, SD = 34.137) and the HL group (M = 56.111, SD = 27.523 but these differences were not significant after applying post hoc corrections.

There was a significant task demands by transition interaction effect at probe three, $F(1, 68) = 14.662, p < .001$, partial $\eta^2 = 0.177$, such that the HL group had significantly lower mental demand ratings (M = 46.944, SD = 23.710) than the HH group (M = 71.389, SD = 26.167), but the LH group had significantly higher mental demand ratings (M = 75.278, SD = 21.793) than the LL group (M = 50.833, SD = 34.821). Further, the HL group had lower ratings than the LH group as well.

Repeated measures ANOVAs on mental demands over the three probes for the HH and LL groups revealed no significant changes over time. However, the HL group exhibited a significant change over time, $F(2, 34) = 10.568, p < .001$, partial $\eta^2 = 0.383$, such that the mental demand ratings decreased from probe one (M = 74.167, SD = 23.089) to probe two (M = 56.111, SD = 27.523), but did not decrease significantly between probe two and probe three (M = 46.944, SD = 23.710). The LH group on the other hand showed a significant effect, $F(2, 34) = 11.211, p < .001$, partial $\eta^2 = 0.397$, such that the mental demand rating increased from probe one (61.389, SD = 24.181) to probe two (M = 78.889.167, SD = 23.674) but did not increase further to probe three (M = 75.278, SD = 21.793).

Temporal demand (TLX). The ANOVA on the temporal demand ratings showed a significant demands by transition interaction, a probe by demands interaction, and a significant three-way interaction, see Table 16.

Table 16.

Exp. 2 Analysis of Variance for Temporal Demand

Source	Type III SS	df	MS	F	*p*	η_p^2
			Within-Subjects Effects			
P	1473.843	2	736.921	2.616	.077	.037
P X D	13550.694	2	6775.347	24.051	.000	.261
P X T	1921.065	2	960.532	3.410	.036	.048
P X D X T	2159.028	2	1079.514	3.832	.024	.053
S X P (D X T)	38312.037	136	281.706			
			Between-Subjects Effects			
D	4.167	1	4.167	.003	.959	.000
T	567.130	1	567.130	.363	.549	.005
D X T	53204.167	1	53204.167	34.088	.000	.334
S (D X T)	106135.185	68	1560.812			

Note. D = (Task) Demands, T = Transition, P = Probe.

The means for the four groups are shown in Figure 16. There was a significant main effect of task demands, $F(1, 68) = 11.737, p = .001$, partial $\eta^2 = 0.147$, as well as a task demands by transition interaction for temporal demand at probe one, $F(1, 68) = 12.031, p = .001$, partial $\eta^2 = 0.150$. The interaction was such that the LL group had lower temporal demand ratings (M = 32.500, SD = 26.748) than the HH (M = 77.500, SD = 30.929), HL (M = 66.111, SD = 25.062), and LH (M = 66.389, SD = 27.696) groups.

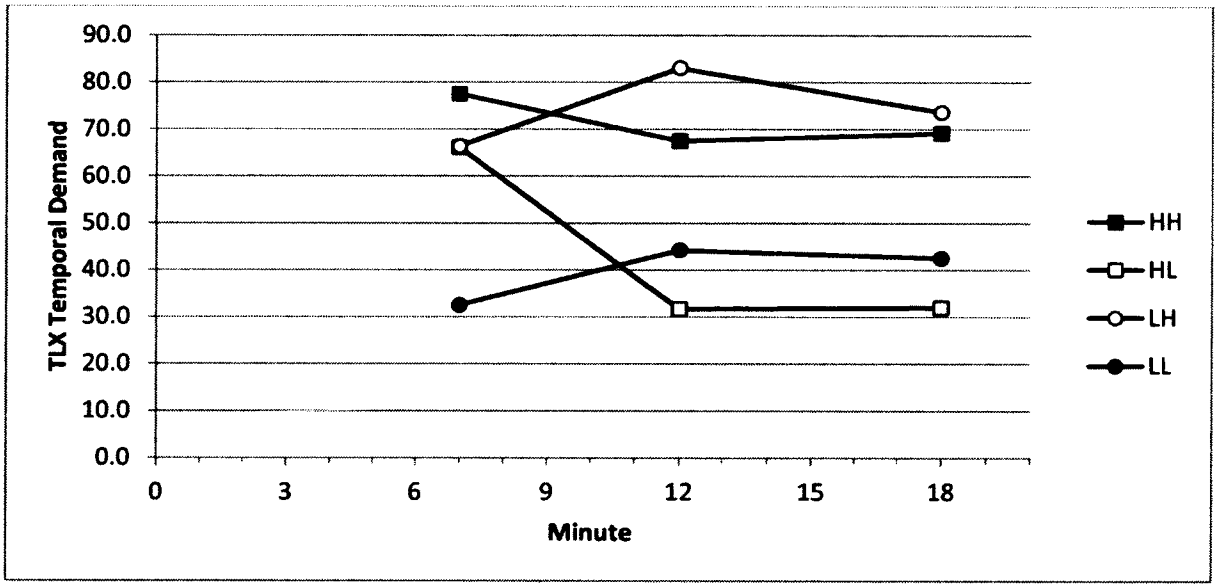

Figure 16. Exp. 2, NASA TLX temporal demand ratings across the three probes.

There was a significant main effect of demands, $F(1, 68) = 5.571, p = .021$, partial $\eta^2 = 0.076$, as well as a task demands by transition interaction effect at probe two, $F(1, 68) = 39.520, p < .001$, partial $\eta^2 = 0.368$, such that the HL group had significantly lower temporal demand ratings (M = 31.667, SD = 16.270) than the HH group (67.500, SD = 31.912), but the LH group had significantly higher temporal demand ratings (M = 83.056, SD = 18.242) than the LL group (M = 44.167, SD = 30.450). Further, the LL has significantly lower ratings than the HH group, and the HL group was lower than the LH group as well.

There was a significant task demands by transition interaction effect at probe three, $F(1, 68) = 29.117, p < .001$, partial $\eta^2 = 0.300$, such that the HL group had significantly lower temporal demand ratings (M = 31.944, SD = 20.518) than the HH group (69.167, SD = 28.193), but the LH group had significantly higher temporal demand ratings (M = 73.611, SD = 23.813) than the LL group (M = 42.500, SD = 33.222). Further, the LL has significantly lower ratings than the HH group, and the HL group was lower than the LH group as well.

Repeated measures ANOVAs on temporal demand scores over the three probes for the HH and LL groups revealed no significant changes over time. There was however a significant change over time for the HL group, $F(2, 34) = 37.261, p < .001$, partial $\eta^2 =$ 0.687, such that the temporal demand ratings decreased from probe one (M = 66.111, SD = 25.062) to probe two (M = 31.667, SD = 16.270), but did not decrease significantly between probe two and probe three (M = 31.944, SD = 20.518). For the LH group there was a significant effect, $F(2, 34) = 8.192, p = .001$, partial $\eta^2 = 0.325$, such that the temporal demand rating increased from probe one (66.389, SD = 27.696) to probe two (83.056, SD = 18.241) but did not change significantly between probe two and probe three (M = 73.611, SD = 23.813).

EXPERIMENT 2 DISCUSSION

The purpose of the second experiment was to test if a change in the magnitude of the transition would yield results consistent with predictions of MIT (Brehm & Self, 1989). In the first experiment, it was found that an LH transition of 30 to 120 events per minute resulted in a loss of task engagement and effort. This result was unexpected and contrary to the results of Helton et al. (2004; 2008), who found an increase in task engagement in response to an LH transition. The task demands in the first experiment may have been so high that they seemed excessive in relation to the expected outcome value by the participants and thus resulted in a withdrawal of effort (Brehm & Self, 1989; Elliot, 1969; Ewing & Fairclough, 2010; Wright et al., 1988). It was hypothesized that a smaller magnitude transition (i.e., 20 to 60 events per minute) could lead to an increase effort investment and replicate Helton et al.'s findings.

Effects on stress and workload. According to the arguments outlined in the discussion of the first experiment, distress should vary according to the task demands if the participants' perceptions of demands are accurate (Matthews et al., 2002). Task engagement and effort, however, were predicted to increase in response to an LH transition and decrease following an HL transition.

Distress. The current experiment found that those who received high task demands had initially higher distress ratings than those who received low demands, as predicted. Over time, the constant demand groups increased their distress ratings while the transition groups did not.

The distress measurement did not show an increase in response to a transition in either direction but rather a change in the direction of the transition. This effect is in accordance with the continuous appraisal hypothesis. However, these results are questionable given the extremely high distress rating reported by the constant low control group. Distress was also the only factor where the LL controls from the first and second experiment differed.

The LL group from the second experiment was examined in further detail to find a possible explanation to their high distress ratings. Scerbo and his colleagues (Sawin & Scerbo, 1995; Scerbo, 1998; Scerbo, 2000; Scerbo et al., 1993) have previously found that the experience of boredom in vigilance tasks is related to not only performance but also experienced workload and stress. A potential explanation could therefore be that the sample, or a subset of the sample, in the LL group in the second experiment had higher boredom proneness (BP; Farmer & Sundberg, 1986) and therefore experienced the low event rate as boring and stressful. Additional statistical analyses were carried out to explore this option and can be found in Appendix E. In summary, there was a significant correlation between the participants rating of how boring they perceived the task to be and their distress ratings from the third probe for the LL group, but not for the HH, HL, or LH groups. The high event rate in the HH group and the change in event rate in the transition groups may have counteracted the participants' experience of boredom in those groups. The eight participants in the LL group who rated the task as most boring (scores of 4 or above) had significantly higher distress at the third probe, but there were no other differences for any stress dimension at any probe. Those eight participants also had higher ratings on the TLX scale of frustration at all three probes but with no differences on any other TLX scale. The frustration subscale has previously been shown to result in high ratings for vigilance tasks where the focus is on task performance (Sawin & Scerbo, 1995). Overall, these results suggest that boredom and frustration may have carried the high distress ratings for the LL group in the second experiment. The relationship between stress, boredom, and workload transitions in vigilance tasks should be explored further in future research.

Task engagement and effort. The task engagement ratings declined over time in the second experiment, just as in the first experiment. However, in contrast to the first experiment it was also found that the LL and LH groups maintained higher overall task engagement than the HH and HL groups over the course of the entire experiment. The subjective effort ratings collected through the NASA TLX questionnaire showed a decline over time for all groups, but also that the LH group had higher effort ratings than the HL group across the entire posttransition part of the experiment.

Overall, these results show partial support for the effort regulation hypothesis. The LH group did not exhibit a marked *increase* in task engagement or effort, but rather a *maintained* high task engagement posttransition. This is in contrast to the steep drop exhibited by the LH group in the first experiment. It should also be noted that the increase in task engagement found by Helton et al. (2008) was based on the difference between a pre- and posttask measurement. Thus, it is not possible to say whether the LH group in their experiment increased their task engagement rating in response to the transition or, as seen in the current experiment, simply maintained a high task engagement from the prior low task demand period.

Further support for the effort regulation hypothesis can be found in the posttask questionnaire, where the participants were asked to rate their effort and performance goals before and after the transition. Whereas the LH group in the first experiment did not show an increase in effort the LH group from the second experiment did. The HL group in the second experiment showed a decline in effort, also as predicted. Interestingly, the

LH group still showed a decrease in their personal performance goals in response to the transition while the HL group did not change their goals, replicating the result from experiment 1. The goal regulation hypothesis was supported but only for the LH group. The effort-regulation theory (Hockey, 1997) is based on a compensatory control mechanism that seeks to minimize the discrepancy between the current performance state and the goal performance state. That the LH group reduced their performance goals indicates that they perceived it was not possible to reach the same performance goal as prior to the transition, even with maintaining high effort. As a result, this group both maintained high effort and reduced their goals.

Physiological response. The results of the current experiment showed that the LF HRV power of all groups increased over time except for the LH group, which remained low. These results are in contrast with the first experiment, where there was a general increase in HRV over time across all groups. The current results indicate that the LH group maintained a higher effort investment over the course of the experiment compared to the other groups. This is further supported by the subjective reports of task engagement and effort, which also showed that the LH group maintained high effort throughout the experiment. The physiological data thus further corroborates the effort regulation hypothesis.

Workload. The hysteresis hypothesis states that the HL group should rate workload and stress higher immediately posttransition as compared to the LL group. This was supported for distress, and the mental and temporal demand ratings in the first experiment. In the second experiment, the HL group also had higher ratings on distress, mental demand, and temporal demand as compared to the LL group one minute posttransition. This supports the hysteresis hypothesis at least initially. Over time, however, the HL group decreased their ratings on all three measures as predicted by the continuous appraisal hypothesis. The mental and temporal demand ratings in the first experiment showed that the LH group immediately increased their ratings posttransition, above the LL control group, and HL group remained high also above the LL control. This could be explained by the fact that an LH transition would immediately overload the task operators' STM, resulting in higher ratings of both mental and temporal demands. The same pattern of workload ratings was found for temporal demand in the current experiment, but not for mental demand. The temporal demand scale may have been more sensitive than the mental demand scale to the event rate manipulation used in the current research. The temporal demand scale asked the participants about the time pressure they experienced dye to the rate or pace of the task, whereas the mental demand scale asked about the mental and perceptual activity required by the task.

Effects on performance. The first experiment indicated that performance varied with task demand. Although a pattern of performance consistent with the mental resource hypothesis prediction was found it was not supported statistically. The effort-performance hypothesis, that performance should vary with reported effort, was not supported either. These two hypotheses were again tested in the second experiment.

The general pattern from experiment one was replicated in the current experiment in terms of perceptual sensitivity and response bias but with some distinct differences. Prior to the transition, the HH and HL groups had lower perceptual sensitivity and more conservative decision bias than the LL and LH groups; as in experiment one. Posttransition, perceptual sensitivity increased for the HL group, and decreased for the

LH group, again replicating experiment one. However, in contrast with experiment one, the two transition groups could not be distinguished from one another at any point posttransition. In terms of decision criterion, the second experiment showed that the HL group adopted a more liberal bias than the HH group during the first six minutes posttransition. The LH group became more conservative following the transition, but could not be distinguished from the other groups.

Overall, the results of the second experiment replicated the same performance pattern as in the first experiment. The mental resource theory was not supported in the second or first experiment. As would be expected, the overall performance differences were smaller in the second experiment as compared to the first, which follows logically from the reduced high task demand level used. This smaller difference made the groups statistically indistinguishable toward the end of the experiment, although the general pattern of the means corresponded to that of the first experiment.

The results from the current experiment showed correlations for the LH group between subjective effort from the TLX questionnaire from the first probe and d' and criterion C scores from the first period. The LH group also showed a significant correlation between d' and task engagement at the third probe. However, as in experiment one these correlations are small and inconsistent over time and groups. The effort-performance hypothesis is therefore not supported by the current results.

Summary. This experiment was conducted to provide a potential explanation for the unexpected results from the first experiment. Based on MIT, it was predicted that a smaller magnitude transition would result in increased effort for the LH group, i.e. support the effort regulation hypothesis. This hypothesis was partially supported by several measures of effort, both subjective and physiological. These measures showed that instead of increasing effort in response to the transition, the LH group maintained a high level of effort throughout the experiment both pre- and posttransition. This finding provides additional context to Ungar's (2008) and Helton et al.'s (2004; 2008) results as they measured effort only pre- and posttask and not at multiple time points. The first experiment also showed partial support for the continuous appraisal hypothesis as well as hysteresis hypothesis, and this was replicated in the current experiment.

CHAPTER V

GENERAL DISCUSSION

The goal of the current research was to investigate the relationship between workload transitions and stress. Workload transitions refer to situations where a person has been performing a task at a certain level of task demand for a period of time but is then suddenly confronted with a substantially different demand level that may be higher or lower. Such dynamic changes in demand levels have been investigated in only a handful of studies, and the results have been conflicting. Hypotheses based on several different theories have been suggested to explain workload transition effects: expectancy theory (Cumming & Croft, 1973), strategic persistence (M. Matthews, 1986), contrast effects (Krulewitz et al., 1975), mental resource theory (Gluckman et al., 1993), and effort-regulation theory (Ungar et al., 2005), among others. The wealth of theories may be traced in part to the way in which the research has evolved. Overall, three major branches of workload transition research can be identified: the hysteresis branch, the workload history branch, and the demand transition branch. Each branch has relied primarily on research within its own branch with no input from the others. Considering all three branches together, research on the stress effects of workload transitions is limited. The current research sought to include findings from all three branches and to explore the topic of stress in workload transitions in particular.

The results of the two experiments showed that task performance follows the imposed task demands with little or no effect of the transition itself. For stress, on the other hand, the results showed effects on different dimensions. Distress changed over time to approach nontransitioned control groups, whereas task engagement and effort depended on both the magnitude and direction of the transition. In response to a large transition, the LH group decreased their task engagement, and there was a general decrease over time for all groups. However, for a smaller magnitude transition a LH transition led to either increased or maintained high task engagement and effort over the entire experiment. This was also shown in physiological indices of LF HRV power. The results also showed that the LH group decreased their performance goals regardless of transition magnitude. Finally, it was also shown that a LH transition provoked an immediate increase in mental and temporal demand ratings whereas a HL condition showed continued high ratings over the same time interval. Over time those demand ratings changed to reflect those of the nontransitioned control groups.

IMPLICATIONS

Transactional stress theory. Transactional stress theory is an umbrella term used here to include the appraisal perspective of Lazarus and Folkman (1984), the adaptive stress model by Hancock and Warm (1989), the effort-regulation theory by Hockey (1997), and the multidimensional view of stress proposed by G. Matthews et al. (1999). Lazarus and Folkman's work on stress as a transaction between the individual and the external world is foundational to contemporary stress research. This perspective emphasizes that each individual will appraise demands placed on them by contrasting the perceived demands with the individual's believed ability to manage said demands. The individual will experience stress if the demands are judged to exceed the individual's coping ability (Lazarus & Folkman, 1984). Further, this mental state of stress can be divided into three main dimensions: task engagement, distress, and worry (G. Matthews et al., 1999). These dimensions of stress are the result of different appraisals and also associated with different modes of coping.

The appraisal process and multidimensional view of stress were key to the current research. The multidimensional view of stress has been applied previously to work on workload transitions (Helton et al., 2004; 2008; Ungar, 2008) but those studies arrived at conflicting results. The work by Helton et al. indicated that workload transitions may affect the stress dimensions differently depending on the direction of the transitions. Ungar, on the other hand, could not replicate Helton et al.'s results and showed no effects on stress. The current work was designed to investigate whether the concept of an appraisal process potentially could resolve those differences. Lazarus and Folkman (1984) emphasized that stress appraisal must be considered as an ongoing process over time. Thus, it follows that the stress effects of a workload transition should be most evident in close temporal proximity to the transition itself but that over time the experienced stress would be determined by the posttransition demands. These predictions were captured in several hypotheses and tested in two experiments. The first experiment showed that the stress reactions did indeed change over time to follow the posttransition demands, supporting Lazarus and Folkman's concept of an ongoing appraisal process. However, the specific effects found by Helton et al. (2004; 2008) were not found, even in close temporal proximity to the transition in the first experiment, mirroring the results of Ungar (2008). Specifically, there was no evidence of a general increase in distress following a transition, nor was there any evidence to indicate that task engagement follows the direction of the transition. The second experiment was therefore necessary to investigate the underlying factors of the transition that should affect the different stress dimensions. Helton et al. (2008) suggested that a transition would result in increased distress because the transition should increase the operator's uncertainty regarding the task whereas Matthews et al. (2002) linked distress to appraisals of high workload and threat. Therefore, a transition that affects the operator's appraisal of the task in terms of uncertainty, perceived workload, or threat may be necessary to replicate Helton et al.'s results. The second effect absent from the first experiment was an increase in task engagement following an increase in task demands, and a decrease in task engagement following a task demand decrease. The first experiment found support for the prediction based on Hockey's (1997) effort-regulation model: the participants who experienced an LH transition decreased their performance goals rather than increasing their effort. Just as with distress, these results provoked the question as to what underlying factors of a transition would lead an operator to respond either by increasing or decreasing their effort and goals. The second experiment appealed to motivational intensity theory (Brehm & Self, 1989) to derive predictions regarding changes in task engagement and effort.

Motivational Intensity Theory. The MIT (Brehm & Self, 1989) relies on the energy-conservation principle and an expectancy-value model to predict the effort invested in a task. The energy-conservation principle states that humans in general aim to avoid wasting energy (Richter, 2013). Thus, according to MIT humans should only mobilize effort to complete a task when the expected value of the outcome is perceived to be greater than the value of the invested effort required to achieve that outcome. The mobilized effort should also be only as high as required by the task and no greater. This is also known as the law of least work. As the effort required for successful task performance increases with increasing task difficulty, it then follows that task demands should be the primary determinants of effort investment (Richter, 2013). Further, this relationship should only hold if task success is possible, and the effort investment is justified by the outcome value (Brehm & Self, 1989; Richter, 2013).

MIT would thus explain the observed withdrawal of effort in response to an LH transition by noting that the participants either judged task success to be unachievable during the high task demand level, or the effort required for successful task performance was not justifiable by the outcome value. To replicate Helton et al.'s (2004; 2008) findings of increased task engagement, the second experiment used a high task demand level where the effort investment was justified by the outcome value. This could be achieved in two alternative ways; by increasing the outcome value, or by reducing the high demand level. Given that Helton et al. found an increase in effort without using incentives, the latter alternative was chosen. A second experiment was thus conducted that replicated the first with one key difference; it used a high demand level of 60 events per minute rather than 120. It was hypothesized that this level of task demand would be high enough to require additional effort beyond the low demand level, but not so high as to deter the participants from investing effort. In contrast to the first experiment, the LH group in the second experiment did indeed report that they increased their effort in response to the transition, as well as having overall higher effort levels than the HL group, and task engagement levels above those of the constant high and HL transition groups. Physiological measurements also indicated that all groups but the LH withdrew effort over time. Overall, these results supported the predictions based on MIT.

Practical implications. Workload transitions are undoubtedly commonplace in many work settings. Consider the commercial aircraft pilot who, due to automation, operates under low task demands for hours of flight time and then faces greater task demands during landing. Consider the surgeon who during the course of a procedure may face phases of higher or lower demands. Consider also the sudden changes in task demands that either professional may experience before, during, and after an emergency. The National Research Council issued a call for research on workload transitions in 1993 (Huey & Wickens, 1993) spurred by concerns for how military troops would react to sudden transitions from extreme underload such as resting to extreme overload in combat.

The current work addressed basic research questions using controlled laboratory experiments and the findings may offer some guidance for future applied research. First, because the current experiment showed that workload transitions may impact some stress dimensions, the effects of stress on the studied task should be established to help guide predictions on how a transition may affect task performance. A task sensitive to changes in distress or task engagement may be more sensitive to workload transitions. The magnitude of the transition is also important. A transition that results in demands that are perceived to be unachievable may encourage a withdrawal of effort whereas a transition of smaller magnitude may encourage greater effort investment. Different tasks may have different ranges of high and low demands, which may act to constrain the possible transition magnitudes. The incentives of task success, or risk of failure, and the skill of the task performer may also influence this relationship. Based on the workload ratings in the current experiments it also seems that an operator who experiences an LH transition will report an increase in workload almost immediately. An operator who experiences an HL transition, however, will persist in reporting high workload during the same time frame. One area where this may be relevant is adaptive automation. One of the potential features of adaptive automation is that the system can recognize overload in the task operator and take control over system functions to reduce the demands on the operator (Rouse, 1988). The current work, however, suggests that the operator may continue to experience a high workload for some time even if the automation reduced the task demands as intended. This may have further implications for the overall design of such systems.

LIMITATIONS

The experimental design used for the current project was based on previous research on workload transitions. Although this design readily lent itself to comparisons to previous studies on the same topic, it also had limitations.

First, the RIP task used in the current research was based on the research by Cox-Fuenzalida and her colleagues (Cox-Fuenzalida, 2007; Cox-Fuenzalida et al., 2004), who used the same task to show performance decrements following a transition. Additionally, Matthews and Campbell's (2009) study on stress using the same task showed that very high event rates could be used, allowing for large magnitude transitions. However, the RIP task proved relatively insensitive to changes in effort. That is, the task may have had a low resource limit (Norman & Bobrow, 1975) meaning that effort invested beyond a certain point would not result in better performance. Successful task performance may therefore have been more dependent on persistence; i.e., an even and constantly applied low level of effort over time, rather than a great amount of invested effort even the high task demand conditions. According to Richter (2013), most MIT research has been concerned with the latter rather than the former. A task with a higher resource limit may prove more sensitive to workload transitions in terms of performance.

Second, one single transition was used rather than multiple transitions, in accordance with the vast majority of studies on workload transitions (Helton et al., 2004; Helton et al., 2008; Ungar et al., 2005; Ungar, 2008; Cox-Fuenzalida et al., 2004; Cox-Fuenzalida & Angie, 2005; Cox-Fuenzalida et al., 2006; Cox-Fuenzalida, 2007; Hauck et al., 2008; Moroney et al., 1995; Gluckman et al., 1993; Krulewitz et al., 1975). A between-subjects design was used as a within-subjects design would expose the participants to multiple transitions and no research to date has systematically investigated the effects of one versus multiple transitions on task performance or stress. If, for instance, a transition leads to increased distress because the task operator is uncertain of the new and future task demands, as suggested by Helton et al. (2008), multiple transitions may act to either increase or decrease this uncertainty and thus affect distress. For instance, a repetitive pattern of transitions may be predictable and reduce uncertainty, whereas a random pattern may increase uncertainty and thereby increase distress. M. Matthews (1986) used both cyclical and random transition patterns and found no effect on performance, yet the effects on subjective states of workload and stress have not been explored.

A third limitation is the lack of training in the current experiment. Cox-Fuenzalida and her colleagues used extensive task training paradigms (see e.g., Cox-Fuenzalida et al., 2004; Cox-Fuenzalida et al., 2006; Hauck et al., 2008), and claimed that this was important for studying workload transitions. Yet research on the relationship between training and transition effects has not been conducted to date. In fact, Hauck et al. (2008) discredited their own research paradigm by noting that their observed stress effects were more likely due to the overall length of the experiment, which included over an hour of training and baseline measurements, rather than a workload transition. The training in the current experiments was thus kept to a minimum, with focus on instructions and a practical example. Pilot studies and the experiments showed no learning effects over time. However, this leaves open the question of how task familiarity and skill may affect the reaction to a transition. It may be that greater familiarity with the task at a specific demand level contributes to a mental model of expected task behavior. A demand transition might thus result in greater uncertainty for those who have more extensive task practice than for those who have less, provided that the task practice does not include prior experience with transitions which would fall into the single versus multiple transition paradigm discussed above.

The current research also relied on task demand transitions within a single task. This is also in line with most previous research on the topic, although an interesting alternative has been explored using transitions between dual and single task conditions (e.g., Ungar, 2008). It is possible that the use of dual-tasking is better suited to study mental resource exhaustion, as indicated by Ungar's research. An extension of Ungar and colleagues' research (Ungar et al., 2005; Ungar, 2008) would be to investigate both dual-to-single as well as single-to-dual transitions, as only the former was used by Ungar. For this type of workload transition, theories on task switching may offer additional insights depending on the specific tasks used.

Task switching. Workload transitions typically concern changes in task demand within the same task. On the other hand, task switching is a more widely studied paradigm where participants switch between qualitatively different types of tasks (Meiran, 2010; Monsell, 2003). Task switching is typically associated with a switch cost, reflected in an increased response time or increase in errors immediately following the switch (Allport, Styles, & Hsieh, 1994; Jersild, 1927; Sohn & Anderson, 2001).

The leading task switch theories attribute the switch cost to either carry-over interference from the previous task set (Allport, Styles, & Hsieh, 1994; Jersild, 1927; Spector & Biederman, 1976), a reconfiguration effort of the current task set (Rogers & Monsell, 1995), or a combination thereof (Meiran, 1996; Meiran, 2010; see also Altmann & Gray, 2008). The concept of "task set" is thus central to the task switching theories. A task set is the set of actions, rules, and goals associated with a particular task (Monsell, 1996; Rogers & Monsell, 1995; Steinhauser, Maier, & Hubner, 2007). A task set can be seen as a more narrow definition of the traditional concept of mental set (Gibson, 1941; Meiran, 2010). The key is that the tasks used in the task switching paradigm require a change in the adopted task set. To achieve this, the tasks used must be distinctly different; for example, by involving different classifications of the same stimuli (e.g., Meiran & Marciano, 2002; Ward, 1982), retrieval or computation of different properties of the stimuli (e.g., Steinhauser, Maier, & Hübner, 2007), subtask order differences (e.g., Philipp & Koch, 2005), different decision rules (e.g., Allport et al., 1994; Schneider & Logan, 2007), or different stimulus-response mappings (Brass et al., 2003; Meiran & Chorev, 2005), among others (see Meiran, 2010; Monsell, 2003). Repeating one task is not associated with switch costs because it does not require a reconfiguration of the task set (Meiran, 1996; 2000). It follows then that a transition in workload within one task should not be associated with a switch cost unless the transition requires a change in the adopted task set; that is, a change in the task actions, rules, or goals. This may not be the case in the majority of workload transition studies to date, but could be relevant for the studies that rely on dual-task conditions.

In terms of stress and task switching, to date three studies have been conducted that investigated the link between the two topics. Steinhauser, Maier, and Hübner (2007) conducted the first study that actively manipulated stress in a task-switching paradigm. They used one task where the participants were asked to indicate whether a presented letter was a vowel or a consonant, and another task where they were asked to rate if a digit was odd or even. A cue was presented for 150 ms to indicate which task the participant would be performing before each trial. Stress was manipulated by administering a high or low difficulty test battery to the different groups prior to the task-switch testing. Steinhauser et al. found that a longer cue-stimulus interval (1,000 ms compared to 200 ms) reduced the switch cost for the low-stress condition but not the high-stress condition. Consequently, Steinhauser et al. suggested that the increased stress induced a change in the reconfiguration strategy and that this result was in line with the effort-regulation model suggested by Hockey (1997). A study by Kofman et al. (2006) did not manipulate stress directly but used a sample of students two weeks prior to a final exams period that exhibited higher levels of state anxiety. However, Kofman et al. found that this "stressed" sample had superior performance in a task-switching paradigm as compared to a sample of non-stressed students, a result opposite of Steinhauser et al. (2007). Plessow, Kiesel, and Kirschbaum (2012) explicitly attempted to reconcile these different results. Plessow and her colleagues used an acute psychosocial stress paradigm, the Trier social Stress Test (TSST; Kirschbaum et al., 1993), together with two number classification tasks. A cue was presented with a CSI of either 200 ms or 1,000 ms to indicate which of two tasks the participants were to perform in the upcoming trial. They found an increased switch cost, in terms of increased error rate, for a stressed group as compared to a control group. The group that received the TSST had an increased error rate but, unlike Steinhauser et al. (2007), Plessow et al. (2012) found no interaction between stress and CSI. Plessow and colleagues stated that their results conform to the idea of priority-dependent resource allocation under stress, as per Hockey's (1997) model. Thus, the three studies to date on stress and task switching appear to rely on the resource-allocation model. However, the stress effects studied in these three articles appear to be task-oriented and likely related to task engagement. Further studies are warranted to investigate other stress dimensions such as distress and worry.

CONCLUSIONS

A review of the workload transition research to date revealed conflicting findings and a plethora of theories to account for those findings. Thus, the current research was designed in part to bring some clarity to the current state of the literature. The main purpose was to investigate the relationship between workload transitions and stress. Previous studies on this topic have had conflicting conclusions such that a transition either increases, decreases, or does not affect different dimensions of stress. Several steps were taken to consolidate the previous findings. First, three different lines of research on the topic of workload transitions were identified and reviewed to provide a broad theoretical base. Second, a contemporary multi-dimensional perspective on stress was adopted to guide the current research, because different dimensions of stress may be affected differently by a transaction. Third, based on the transactional stress theory, one key methodological difference among the previous studies was identified; namely, the time from the transition to the measurement of subjective stress. Fourth, both subjective and physiological indices of workload and stress were used to provide a more comprehensive view of the effects of a workload transition.

Data from the two experiments revealed two important findings. First, it was shown that individuals will adapt to the new demands over time with continued task performance. Stress and estimates of workload will shift toward the levels exhibited by non-transitioned controls. This is in line with the notion of a continuous stress appraisal process as suggested by Lazarus and Folkman (1984). Previous research on workload transitions has used a wide range of times between the transition and the administration of subjective questionnaires to measure the effects of the transition. The current research shows that it is important to consider how long transition effects may persist to determine the timing of measurements. Ideally, several measurements over time should be used to determine how, for example, stress develops following a transition. Second, the absolute magnitude of the transition is also important. Through the two experiments it was shown that a large transition that quadrupled the task demands resulted in a qualitatively different coping response than a more moderate transition that merely doubled the demands. The magnitude of the transition affected primarily the effort exhibited by the task performers. The motivational intensity theory proved useful in explaining and predicting these effects, but further research is needed to explore the interaction between transition magnitude and other factors that might influence the different stress dimensions.

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APPENDIX A

POSTTASK QUESTIONNAIRE – EXPERIMENT 1

Please complete the following questionnaire as **ACCURATELY** and **HONESTLY** as you can. Keep in mind that this questionnaire covers all versions of the experiment, including conditions that you were not exposed to. Some questions are relevant only to other participants. Therefore, you should consider **CAREFULLY** what is true for just you and your experience in the experiment today.
All of the questions only concern **THE ACTUAL TASK** (after the practice and 10-minute rest period) and **NOT THE REST PERIOD OR PRACTICE SESSION.**

1) Overall, I found the task to be (check all that apply):

□ Boring	□ Challenging	□ Unpredictable	□Relaxing	□ Draining
□ Threatening	□ Taxing	□ Easy	□ Predictable	□ Soothing
□ Hard	□ Exhausting	□ Demanding	□ Enjoyable	□ Stressful

2) I my opinion, the difficulty of the task remained **consistent** throughout the experiment (circle one):

Completely Disagree				Completely Agree
1	2	3	4	5

3A) Did any aspects of the task change **NOTICEABLY** during the experiment? (check one):

□ No, the task did not change	□ Yes, the digits changed color	□ Yes, the digits sped up
□ Yes, the digits slowed down	□ Yes, there were fewer signals	□ Yes, there were more signals
□ Yes, the digits grew larger	□ Yes, the digits grew smaller	□ Yes, the digits turned upside-down

If you checked Yes, proceed to Question 3B. If you checked No, go to Question 4.

3B) If you noticed a change in the task, how easy or hard was it to **notice** that change? (circle one):

Very Easy to Notice				Very hard to Notice
1	2	3	4	5

3C) If you noticed a change, how did the change affect the task or your feelings about the task? (check all that apply): It made the task…

□ more boring	□ more challenging	□ more unpredictable	□ more relaxing
□ more draining	□ more threatening	□ more taxing	□ easier
□ more predictable	□ more soothing	□ harder	□ more exhausting
□ more demanding	□ more enjoyable	□ more stressful	□ none of the above

3D) If you noticed a change, how did the change affect your **effort**? (circle **one before** and **one after**):

Before the change					After the change				
Low Effort			High Effort		Low Effort			High Effort	
1	2	3	4	5	1	2	3	4	5

3E) If you noticed a change, how did the change affect your **goal**? (circle **one before** and **one after**):

(Low goal = catch no or a few signals; High goal = catch all signals)

Before the change					After the change				
Low Goal			High Goal		Low Goal			High Goal	
1	2	3	4	5	1	2	3	4	5

4) If you did **NOT** notice a change, how did you experience the task **OVER TIME**? (check all that apply):

Over time, the task became…

□ more boring	□ more challenging	□ more unpredictable	□ more relaxing
□ more draining	□ more threatening	□ more taxing	□ easier
□ more predictable	□ more soothing	□ harder	□ more exhausting
□ more demanding	□ more enjoyable	□ more stressful	□ none of the above

5) If you have any other opinions or thoughts, please share them below:

____

____

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____

____

APPENDIX B

POSTTASK QUESTIONNAIRE – EXPERIMENT 2

Please complete the following questionnaire as **ACCURATELY** and **HONESTLY** as you can. Keep in mind that this questionnaire covers all versions of the experiment, including conditions that you were not exposed to. Some questions are relevant only to other participants. Therefore, you should consider **CAREFULLY** what is true for just you and your experience in the experiment today.
All of the questions only concern **THE ACTUAL TASK** (after the practice and 10-minute rest period) and **NOT THE REST PERIOD OR PRACTICE SESSION.**

1) Overall, I found the task to be (check all that apply):

□ Boring	□ Challenging	□ Unpredictable	□Relaxing	□ Draining
□ Threatening	□ Taxing	□ Easy	□ Predictable	□ Soothing
□ Hard	□ Exhausting	□ Demanding	□ Enjoyable	□ Stressful

2) I my opinion, the difficulty of the task remained **consistent** throughout the experiment (circle one):

Completely Disagree				Completely Agree
1	2	3	4	5

3A) Did any aspects of the task change **NOTICEABLY** during the experiment? (check one):

□ No, the task did not change □ Yes, the digits changed color □ Yes, the digits sped up
□ Yes, the digits slowed down □ Yes, there were fewer signals □ Yes, there were more signals
□ Yes, the digits grew larger □ Yes, the digits grew smaller □ Yes, the digits turned upside-down

If you checked Yes, proceed to Question 3B. If you checked No, go to Question 4.

3B) If you noticed a change in the task, how easy or hard was it to **notice** that change? (circle one):

Very Easy to Notice				Very hard to Notice
1	2	3	4	5

3C) If you noticed a change, how did the change affect the task or your feelings about the task? (check all that apply): It made the task…

□ more boring	□ more challenging	□ more unpredictable	□ more relaxing
□ more draining	□ more threatening	□ more taxing	□ easier
□ more predictable	□ more soothing	□ harder	□ more exhausting
□ more demanding	□ more enjoyable	□ more stressful	□ none of the above

3D) If you noticed a change, how did the change affect your **effort**? (circle **one before** and **one after**):

Before the change					After the change				
Low Effort			High Effort		Low Effort			High Effort	
1	2	3	4	5	1	2	3	4	5

3E) If you noticed a change, how did the change affect your **goal**? (circle **one before** and **one after**):

(Low goal = catch no or a few signals; High goal = catch all signals)

Before the change					After the change				
Low Goal			High Goal		Low Goal			High Goal	
1	2	3	4	5	1	2	3	4	5

3F) At what point in time did the task change? (check one):

□ In the first third of the experiment □ In the middle third of the experiment
□ In the last third of the experiment □ After each signal □ After each response
□ After each time I missed a signal □ Continuously, in small increments
□ Whenever I stopped focusing on the screen

4) If you did **NOT** notice a change, how did you experience the task **OVER TIME**? (check all that apply):

Over time, the task became...

□ more boring	□ more challenging	□ more unpredictable	□ more relaxing
□ more draining	□ more threatening	□ more taxing	□ easier
□ more predictable	□ more soothing	□ harder	□ more exhausting
□ more demanding	□ more enjoyable	□ more stressful	□ none of the above

5) If you have any other opinions or thoughts, please share them below:

____

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____

APPENDIX C

RESULTS OF THE POSTTASK QUESTIONNAIRE IN EXPERIMENT 1

Table 17.

Experiment 1 Means and SEs from Question 1

Item	HH	HL	LH	LL
Boring	1.667 (0.443)	2.389 (0.425)	1.500 (0.374)	2.737 (0.510)
Challenging	4.444 (0.271)	3.667 (0.288)	4.167 (0.239)	2.316 (0.371)
Unpredictable	2.722 (0.497)	3.222 (0.429)	3.444 (0.392)	3.000 (0.485)
Relaxing	0.222 (0.101)	0.889 (0.275)	0.333 (0.144)	0.842 (0.364)
Draining	2.556 (0.444)	2.444 (0.392)	2.556 (0.457)	2.421 (0.452)
Threatening	0.611 (0.325)	0.500 (0.279)	0.333 (0.288)	0.105 (0.076)
Taxing	1.722 (0.490)	1.944 (0.459)	1.944 (0.467)	1.421 (0.407)
Easy	0.444 (0.166)	1.944 (0.403)	0.833 (0.208)	2.316 (0.458)
Predictable	0.611 (0.282)	1.389 (0.373)	0.722 (0.309)	1.053 (0.338)
Soothing	0.167 (0.090)	0.556 (0.253)	0.222 (0.104)	0.579 (0.295)
Hard	3.944 (0.347)	3.111 (0.398)	2.944 (0.488)	0.895 (0.209)
Exhausting	2.389 (0.465)	2.000 (0.463)	2.056 (0.474)	1.053 (0.400)
Demanding	3.667 (0.379)	2.889 (0.431)	3.333 (0.343)	2.000 (0.412)
Enjoyable	0.333 (0.140)	1.222 (0.368)	0.722 (0.217)	0.947 (0.249)
Stressful	2.778 (0.432)	2.167 (0.392)	2.611 (0.441)	1.263 (0.332)

Note: Means with SE in parenthesis.

Table 18.

Experiment 1 Means and SEs from Question 2

	HH	HL	LH	LL
Consistency	4.222 (0.236)	2.278 (0.232)	2.389 (0.29)	3.526 (0.273)

Note: Means with SE in parenthesis.

For question 3A, 22.2% of the HH group and 31.6% of the LL group correctly noted that the task did not change. 66.7% of the HH group said that they believed the task sped up, and 11.1% thought it slowed down. For the LL group, 47.4% believed the task sped up, 5.3% that it slowed down, 10.5% that there were fewer signals and 5.3% that there were more signals. In contrast, 88.9% of the HL group and 100% of the LH group correctly noted that the task had slowed down or increased, respectively. 11.1% of the HL group believed that the task has sped up rather than slowed down.

On question 3B, how easy or hard was the transition to notice with 1 being "very easy" and 5 "very hard", the HL group scored 1.222 (SE = 0.203) and so did the LH group (SE = 0.173).

Table 19.

Experiment 1 Means and SEs from Question 3C.

Item	HL	LH
Boring	1.500 (0.395)	0.389 (0.194)
Challenging	1.167 (0.456)	4.556 (0.176)
Unpredictable	1.111 (0.436)	2.944 (0.525)
Relaxing	1.778 (0.442)	0.222 (0.107)
Draining	1.000 (0.402)	2.778 (0.497)
Threatening	0.333 (0.297)	0.611 (0.365)
Taxing	0.611 (0.322)	1.944 (0.511)
Easier	3.000 (0.485)	0.278 (0.115)
Predictable	2.056 (0.424)	0.444 (0.176)
Soothing	0.833 (0.376)	0.222 (0.107)
Harder	1.167 (0.472)	4.444 (0.214)
Exhausting	0.944 (0.326)	2.667 (0.477)
Demanding	0.944 (0.433)	4.111 (0.331)
Enjoyable	1.278 (0.409)	0.333 (0.149)
Stressful	0.944 (0.397)	3.333 (0.477)

Note: Means with SE in parenthesis.

On question 3D, the HL group rated their effort (from 1 to 5) before the transition as 4.111 (SE = 0.284) and after the transition as 3.500 (SE = 0.305). The LH group rated their effort as 3.667 (SE = 0.378) before the transition and 3.444 (SE = 0.451) after. If the two participants who said they noticed a LH transition when they in fact experienced a HL transition are excluded, the mean of the HL group is 4.313 (SE = 0.218) before and 3.313 (SE = 0.254) after.

On question 3E, the HL group rated their performance goals (from 1 to 5) before the transition as 3.778 (SE = 0.337) and after the transition as 3.833 (SE = 0.319). The LH group rated their performance goals as 4.667 (SE = 0.183) before the transition and 3.333 (SE = 0.367) after.

Table 20.

Experiment 1 Means and SEs from Question 4

Item	HH	LL
Boring	0.944 (0.366)	1.611 (0.500)
Challenging	3.389 (0.493)	2.056 (0.467)
Unpredictable	1.889 (0.471)	1.556 (0.472)
Relaxing	0.111 (0.076)	0.500 (0.279)
Draining	1.889 (0.464)	1.278 (0.462)
Threatening	1.389 (0.436)	0.056 (0.057)
Taxing	1.278 (0.449)	0.611 (0.302)
Easier	0.333 (0.162)	1.278 (0.469)
Predictable	0.500 (0.294)	0.944 (0.403)
Soothing	0.111 (0.076)	0.444 (0.279)
Harder	3.111 (0.523)	0.944 (0.282)
Exhausting	2.333 (0.485)	0.778 (0.377)
Demanding	3.389 (0.405)	1.389 (0.391)
Enjoyable	0.111 (0.076)	0.333 (0.186)
Stressful	2.556 (0.452)	1.222 (0.328)

Note: Means with SE in parenthesis.

APPENDIX D

RESULTS OF THE POSTTASK QUESTIONNAIRE IN EXPERIMENT 2

Table 21.

Experiment 2 Means and SEs from Question 1

Item	HH	HL	LH	LL
Boring	1.944 (0.098)	2.222 (0.104)	1.333 (0.074)	2.722 (0.100)
Challenging	3.000 (0.099)	3.389 (0.079)	3.667 (0.071)	2.278 (0.083)
Unpredictable	2.556 (0.105)	3.000 (0.101)	3.056 (0.121)	1.889 (0.106)
Relaxing	0.833 (0.051)	0.889 (0.078)	0.889 (0.050)	0.778 (0.059)
Draining	2.667 (0.109)	1.833 (0.084)	2.389 (0.094)	1.778 (0.100)
Threatening	0.444 (0.055)	0.833 (0.077)	0.611 (0.061)	0.333 (0.043)
Taxing	2.000 (0.109)	1.556 (0.081)	1.833 (0.101)	1.111 (0.099)
Easy	1.222 (0.056)	1.667 (0.071)	1.056 (0.048)	2.444 (0.103)
Predictable	1.167 (0.088)	0.722 (0.057)	0.944 (0.086)	1.389 (0.092)
Soothing	0.333 (0.033)	0.833 (0.072)	0.500 (0.034)	0.389 (0.039)
Hard	2.611 (0.097)	2.611 (0.088)	3.167 (0.067)	1.111 (0.074)
Exhausting	2.333 (0.101)	2.222 (0.084)	2.333 (0.091)	1.333 (0.083)
Demanding	2.889 (0.087)	2.611 (0.090)	3.333 (0.091)	1.778 (0.086)
Enjoyable	0.833 (0.048)	0.778 (0.059)	1.444 (0.058)	1.333 (0.091)
Stressful	2.556 (0.106)	2.500 (0.110)	2.778 (0.068)	1.944 (0.094)

Note: Means with SE in parenthesis.

Table 22.

Experiment 2 Means and SEs from Question 2

	HH	HL	LH	LL
Consistency	3.556 (0.084)	3.000 (0.066)	2.389 (0.072)	3.722 (0.057)

Note: Means with SE in parenthesis.

For question 3A, 16.7% of the HH group and 66.7% of the LL group correctly noted that the task did not change. 66.7% of the HH group said that they believed the task sped up, and 11.1% thought it slowed down. For the LL group, 22.2% believed the task sped up, 5.6% that it slowed down and 5.6% that there were fewer signals. In contrast, 72.2% of the HL group and 94.4% of the LH group correctly noted that the task had slowed down or increased, respectively. 27.8% of the HL group believed that the task has sped up rather than slowed down, and 5.6% of the LH group believed the task slowed down rather than speed up.

On question 3B, how easy or hard was the transition to notice with 1 being "very easy" and 5 "very hard", the HL group scored 1.944 (SE = 0.052) and the LH group 1.555 (SE = 0.044).

Table 23.

Experiment 2 Means and SEs from Question 3C

Item	HL	LH
Boring	1.611 (0.103)	0.611 (0.081)
Challenging	1.722 (0.099)	3.889 (0.074)
Unpredictable	1.722 (0.091)	2.444 (0.121)
Relaxing	1.278 (0.071)	0.222 (0.024)
Draining	1.667 (0.103)	1.722 (0.091)
Threatening	0.667 (0.066)	0.667 (0.069)
Taxing	0.778 (0.073)	2.500 (0.112)
Easier	2.389 (0.106)	0.222 (0.041)
Predictable	1.056 (0.082)	0.556 (0.069)
Soothing	1.500 (0.086)	0.222 (0.041)
Harder	1.167 (0.090)	3.389 (0.101)
Exhausting	1.056 (0.072)	2.056 (0.094)
Demanding	1.167 (0.072)	3.167 (0.098)
Enjoyable	0.778 (0.073)	0.944 (0.075)
Stressful	1.000 (0.083)	3.167 (0.072)

Note: Question 3C from Experiment 1. Means with SE in parenthesis.

On question 3D, the HL group rated their effort (from 1 to 5) before the transition as 3.944 (SE = 0.297) and after the transition as 3.000 (SE = 0.303). The LH group rated their effort as 2.9444 (SE = 0.297) before the transition and 4.222 (SE = 0.263) after. If the five participants who said they noticed an LH transition when they in fact experienced an HL transition are excluded, the mean of the HL group is 4.462 (SE = 0.243) before and 2.615 (SE = 0.311) after. If the one participant who said they noticed an HL transition when they in fact experienced an LH transition, the mean of the HL group is 2.824 (SE = 0.287) before and 4.176 (SE = 0.274) after.

On question 3E, the HL group rated their performance goals (from 1 to 5) before the transition as 3.888 (SE = 0.227) and after the transition as 3.778 (SE = 0.263). The LH group rated their performance goals as 4.222 (SE = 0.173) before the transition and 3.611 (SE = 0.354) after.

Question 3F asked the participants who said they experienced a transition to specify when during the experiment that transition occurred. Among the alternatives, the alternatives for "first third of the experiment" and "middle third of the experiment" may both be considered correct for the HL and LH groups, as the transition manipulation occurred at the end of the 6^{th} minute in the 18 minute long experiment. The results showed that among those in the HH group who claimed to have experienced a transition, 7% said this transition occurred in the first third of the experiment, 7% in the middle third, 7% in the last third, 7% after each signal, 20% after each response, 27% after each miss, and 27% said it was a continuous transition throughout the entire experiment. For those in the LL group who claimed to have experienced a transition, 50% said the transition occurred in the middle third, 17% in the last third, 17% after each response, and

17% continuously throughout the experiment. For the HL group, 28% claimed they experienced a transition in the first third, 39% in the middle third, 11% in the last third, 6% after each response, 6% after each miss, and 11% said the transition was continuous. For the LH group, 17% said the transition occurred in the first third, 33% in the middle third, 6% in the final third, 11% after each response, and 33% continuously.

Table 24.

Experiment 2 Means and SEs from Question 4

Item	HH	LL
Boring	1.444 (0.077)	2.500 (0.113)
Challenging	2.778 (0.100)	2.000 (0.095)
Unpredictable	1.833 (0.112)	1.500 (0.099)
Relaxing	0.944 (0.084)	0.444 (0.048)
Draining	2.222 (0.110)	1.722 (0.109)
Threatening	0.889 (0.085)	0.556 (0.058)
Taxing	1.556 (0.106)	1.167 (0.094)
Easier	0.889 (0.063)	1.389 (0.094)
Predictable	0.944 (0.082)	1.722 (0.109)
Soothing	0.556 (0.051)	0.333 (0.043)
Harder	2.111 (0.122)	1.389 (0.096)
Exhausting	1.778 (0.105)	2.056 (0.110)
Demanding	2.778 (0.107)	1.667 (0.108)
Enjoyable	0.722 (0.060)	0.611 (0.069)
Stressful	2.389 (0.116)	1.278 (0.087)

Note: Means with SE in parenthesis.

APPENDIX E

ADDITIONAL ANALYSES FOR THE LL GROUP IN EXPERIMENT 2

Table 25.

Correlations between Task Boredom Ratings from the Posttask Questionnaire and Distress at Probe Three

	HH	HL	LH	LL
Pearson *r*	.195	.358	.132	.589**

*Note: ** indicates p < .01. All n = 18.*

The following analyses were conducted using 2-tailed t-tests.

Table 26.

Comparison between High-Boredom Participants and Low-Boredom Participants on SSSQ Ratings

		HB	LB	*p*	Cohen's d
Probe 1	Task Engagement	0.415 (1.149)	0.498 (0.887)	.865	0.081
	Distress	1.005 (2.780)	-0.067 (0.587)	.249	0.534
	Worry	-1.079 (1.422)	-0.322 (0.755)	.165	0.665
Probe 2	Task Engagement	0.046 (1.635)	0.406 (0.960)	.567	0.268
	Distress	2.052 (3.333)	0.503 (1.370)	.198	0.608
	Worry	-1.280 (1.687)	-0.556 (0.922)	.262	0.533
Probe 3	Task Engagement	-0.438 (1.248)	-0.314 (1.381)	.845	0.095
	Distress	3.601 (2.493)	1.173 (1.816)	.029*	1.114
	Worry	-1.353 (1.525)	-0.644 (0.946)	.243	0.559

*Note: Means with SD in parenthesis. * indicates p < .05. HB = High-boredom (n = 8) and LB = Low-boredom (n = 10).*

Table 27.

Comparison between High-Boredom Participants and Low-Boredom Participants on TLX Ratings.

		HB	LB	*p*	Cohen's d
Probe 1	Mental Demand	64.375 (30.873)	51.500 (27.391)	.363	0.441
	Temporal Demand	36.250 (34.821)	29.500 (19.643)	.610	0.239
	Performance	23.750 (19.039)	22.500 (20.310)	.896	0.064
	Effort	73.125 (29.269)	60.500 (28.426)	.369	0.438
	Frustration	55.000 (34.434)	15.000 (10.801)	.003**	1.567
Probe 2	Mental Demand	56.875 (37.885)	57.500 (32.935)	.971	0.018
	Temporal Demand	36.875 (26.314)	50.000 (33.582)	.380	0.435
	Performance	20.000 (15.811)	27.000 (19.032)	.417	0.400
	Effort	50.625 (37.363)	63.000 (33.682)	.471	0.348
	Frustration	55.000 (38.545)	18.000 (23.357)	.023*	1.161
Probe 3	Mental Demand	54.375 (34.583)	48.000 (36.606)	.712	0.179
	Temporal Demand	38.750 (28.253)	45.500 (37.966)	.682	0.202
	Performance	27.500 (27.516)	31.000 (22.211)	.769	0.140
	Effort	33.125 (30.23)	62.500 (33.850)	.073	0.915
	Frustration	67.500 (35.657)	26.000 (31.073)	.018*	1.241

*Note: Means with SD in parenthesis. * indicates p < .05, ** indicates p < .01. HB = High-boredom (n = 8) and LB = Low-boredom (n = 10).*

VITA

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Education

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Work Experience

2014-Current	**Researcher**, Swedish Institute for Computer Science, East
2010-2014	**Research Assistant**, Old Dominion University
2010-2011	**Teaching Assistant**, Old Dominion University
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2009-2010	**Teaching Assistant**, Linköping University
2009	**Research Assistant**, Linköping University
2008-2009	**Software Developer**, Santa Anna Research Institute
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Selected Publications

Prytz, E. & Scerbo, M. (2012). Spatial Judgments in the Horizontal and Vertical Planes from Different Vantage Points. *Perception, 41(1)*, 26-42.

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