UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

A MULTILEVEL APPROACH TOWARD RELATING SUBJECTIVE WORKLOAD AND EFFORT TO PERFORMANCE DURING STABLE AND AFTER SHIFTS IN TASK DEMAND

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

Degree of

DOCTOR OF PHILOSOPHY

By

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Norman, Oklahoma
2015

A MULTILEVEL APPROACH TOWARD RELATING SUBJECTIVE WORKLOAD
AND EFFORT TO PERFORMANCE
DURING STABLE AND AFTER SHIFTS IN TASK DEMAND

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF PSYCHOLOGY

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I would like to dedicate my dissertation to my parents Steve and Elaine Mracek for always believing in me.

I also would like to dedicate this dissertation to Bevin Cheyenne Smieja for all the love along the way.

Acknowledgements

I would like to express deep appreciation to my committee chair, Professor Eric Anthony Day. Without his guidance this dissertation would not have been possible.

I would also like to express gratitude toward Mathew J Stein for helping to develop the software necessary for this dissertation.

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Abstract

This laboratory study tested a causal model of the effects of changes in perceptions of subjective workload and effort in relation to performance during stable and after shifts in task demand. Accordingly, this study addressed the need for within-person examinations of how individuals as a function of self-regulation respond to shifts in task demand. Participants were 198 university undergraduates who were trained to perform a computer game representing a complex decision-making environment. Subjective workload, subjective cognitive effort, and objective performance were concurrently measured at regular intervals (i.e., every 60 s) in five 10-minute trials, two of which involved a shift, either an increase or decrease, in task demand. Relationships between variables were examined using a longitudinal, multilevel approach suitable for disaggregating within-person (i.e., state) and between-person (i.e., trait) components. The proposed model reflecting inconsistent mediation was consistently supported when conditions involved stable task demands. Specifically, in trials involving stable demands, changes in subjective workload had positive indirect effects but stronger negative direct effects on performance. However, there was little support for inconsistent mediation in trials involving shifts in task demand. Rather, dynamic effects were observed as a function of the shift in task demands such that changes in subjective workload showed increasingly positive effects on performance after increases in task demand but increasingly negative effects after decreases in task demand. In general, this research demonstrated the need to account for indirect effects such as the volitional aspect of control (i.e., effort) and dynamic effects as a function of shifts in task demand

when trying to understand the relationship between changes in subjective workload and performance.

Introduction

Stress, as a consequence of sustained attention or changing task demand, requires adaptation for successful performance to be achieved (Hancock & Warm, 1989; Hockey, 1986). Adaptation is a function of variability in the process of self-regulation (Hockey, 1986), within- and between-persons (Helton, Funke, & Knott, 2014), and involves different cognitive processes including volition (Karoly, 1993). Cybernetic-systems theories, specifically perceptual control theory (Powers, 1973, 1978), explain behavior as a function of self-regulation, more specifically, the interrelationships between subsystem properties (e.g., comparator, effector, output) (Vancouver, 2005). Psychological constructs (e.g., subjective workload/perceived difficulty, subjective cognitive effort) are useful for providing indicators of these subsystems, especially when assessed at regular frequent intervals. Repeated assessments allow for longitudinal, multilevel approaches (i.e., disaggregation; (Curran & Bauer, 2011) which are well suited for capturing *state* (i.e., within-person) and *trait-like* (i.e., between-person) differences (Helton et al., 2014; Mracek, Arsenault, Day, Hardy III, & Terry, 2014). Research is needed involving conditions of stress that examines how changes in states are central to the dynamic interrelationships among control theory's subsystem properties.

Therefore, the general purpose of this laboratory study was to test a causal model of how changes in states related to self-regulation, specifically the control theory subsystem indicators involved in the stress-motivation-performance relationships, are related to performance during stable and after shifts in task demand. In particular, the present study was designed to extend the work of Mracek et al. (2014) who showed the relationship between subjective workload and performance varied across periods of performance in relation to the duration of performance following shifts in task demand (immediate vs. more downstream intervals). Specifically, they showed that negative within-person subjective workload effects on performance, reflecting capabilities being exceeded, were more likely to occur in downstream performance intervals following increases in task demand as opposed to intervals either immediately following increases or in intervals after decreases in task demand.

The present study extends Mracek et al. (2014) by (1) accounting for volition (i.e., effort), (2) examining and comparing within-person relationships in stable versus following shifts in task demand, and (3) better disentangling these relationships in relation to the duration of performance following shifts in task demand. Specifically, in Mracek et al. (2014), increases in task demand were temporary, thus comparisons between immediate versus downstream effects were confounded by decreases in task demand. However, in the present study, shifts in task demand were sustained over the remainder of the performance intervals within a trial. Accordingly, this study provides a comparison of immediate versus downstream effects that were not confounded by another (opposing) shift in task demand. Using a computer game representing a complex decision-making environment, subjective workload, subjective cognitive effort, and performance were concurrently measured at regular intervals (i.e., every 60

s) in five 10-minute trials, two of which involved a shift, either an increase or decrease, in task demand midway in the trial that was sustained for the remaining five minutes. As such, in the trials that involved a shift in task demand, subjective workload, subjective effort, and performance were measured in intervals preceding and following objective shifts in task demand.

Consistent with control theory, I expected that changes in subjective workload would be positively related to changes in effort, and in turn changes in effort would be positively related to performance. Furthermore, I tested the proposition that the relationship between subjective workload and performance through effort would be characteristic of inconsistent mediation (i.e., suppression; [Davis, 1985]) such that the indirect (positive relationship) and direct (negative relationship) effects of subjective workload on performance would have opposite signs (Cliff & Earleywine, 1994; Tzelgov & Henik, 1991). Further, I expected the positive indirect effect of increases in subjective workload on performance via increases in effort would be moderated by shifts in task demand and the duration of performance following the shifts. Specifically, I tested the proposition that this indirect relationship would be weaker following increases in task demand primarily when the relationship would be examined downstream rather than immediately following the increases. In particular, I expected a breakdown in the link between effort and performance downstream from increases in task demand. Figure 1 shows my hypothesized model.

Self-regulation in Relation to Shifts in Task Demand and Performance Duration

Toward the goal of maintaining a favorable internal environment, the self-regulatory control system is characterized by a feedback loop consisting of subsystems (e.g., comparator, effector, output) and interrelationships between the subsystems (Vancouver, 2005). The *comparator* subsystem subjectively perceives the fit between the current status of one's system and the desired status of the system (Klein, 1989; Powers, 1973) as perceptions are likely construed vis-à-vis a comparison between a personal, referent standard and, if accessible, one's knowledge of his or her current performance (Karoly, 1993). If there is a mismatch (i.e., disturbance) between current and desired states, then the *effector* subsystem is tasked with reducing the discrepancy via effort. As a result of changes in cognition or task behavior (i.e., the effector), the *output* (i.e., performance) of the system changes. Next, by way of the feedback loop, the changed state is then again compared to the system standard via the comparator. This self-regulatory process of perceiving, comparing, and effecting is thought to repeat until the disturbance is resolved. Psychological constructs (e.g., subjective workload/perceived difficulty, subjective cognitive effort) are useful for providing markers or parameters in models of the subsystem indicators (Vancouver, 2005).

The discrepancy-reducing control framework is especially relevant for explaining behavior when external environments are characterized by instability such as when encountering a change in task requirements (Karoly, 1993; Richardson, 1991). That is, disturbances are more likely to occur as a function of a shift in task demand, wherein the interrelationships between subjective workload, effort, and performance are especially salient. In theory, with respect to task complexity, a shift in task demand changes the nature of how one needs to organize and execute the actions necessary for success (Wood, 1986). If habitual action patterns are less effective, then control processes involved in self-regulation are typically initiated (Karoly, 1993). As such, goal striving is made salient and stress serves to focus attention (Karoly, 1993).

When trying to understand the interrelationships between subjective workload, effort, and performance, the nature of information-processing demands need to be considered (Kanfer & Ackerman, 1989). Specifically, a higher level of objective task demand requires greater resources for tasks in which increases or decreases in the amount of attention allocated result in differences in objective task performance (i.e., resource-limited tasks; Norman & Bobrow, 1975). From a task complexity perspective (Wood, 1986), a higher level of task demand is characterized by more distinct acts that need to be executed, and more information cues that must be processed in the performance of those acts. Likewise, when the number of required acts increase or the nature of the needed acts changes, knowledge and skill requirements are higher in relation to the required activities and events (Wood, 1986). Similarly, greater levels of task demand make the coordination of inputs and task products more challenging by way of timing, frequency, and location requirements. In terms of control theory, as a function of the greater need of attentional resources to process information cues, execute distinct acts, and coordinate inputs and products, the referent standard is more challenging to meet, hence a discrepancy is more likely to occur. In terms of cognitive-energetic theory, deviations (i.e., within-person effects) in subjective experiences (e.g., subjective workload/perceived difficulty) reflect different control states in relation to the magnitude and direction of their relationships with performance in relation to shifts in task demand (e.g., appropriate vs. overload and dynamic stability vs. dynamic instability; [Hancock & Warm, 1989; Hockey, 1984, 1986]). In this way, changes in subjective states capture the status of the comparator subsystem, which in turn influences changes in effort reflected in the effector subsystem.

The Effect of Subjective Workload on Effort

A consideration of the aftereffects of stress on performance (Cohen, 1980) highlights the need to better account for subjective control states (Hockey, 1986; Hockey & Hamilton, 1983). As such, subjective experiences associated with performing a task, especially when assessed at frequent intervals, characterize two similar if not congruent constructs: subjective workload, which is commonly measured with a more behaviorally anchored rating scale (e.g., "Indicate the level of workload you were experiencing just before the screen froze." 1 = "*Little to do; little demands*;" 9 = *"Too much to do; overloaded; postponing some tasks*;" [Grech, Neal, Yeo, Humpreys, & Smith, 2009; Mracek et al., 2014; Tattersall & Foord, 1996]) and perceived difficulty, which is commonly measured with a graphic rating scale (e.g., "How difficult did you find the task just before the screen froze? 0 = "*not at all;*" 10 = "*extremely difficult/extremely hard*;" [Yeo & Neal, 2004, 2008]). Subjective workload better represents how an individual is handling task demand compared to the more task-oriented framing characterized by perceived difficulty. Below, I consider perceived difficulty's relationship with effort in addition to subjective workload's relationship with effort.

Subjective workload, or perceptions of one's capacity to meet task demand (i.e., perceived difficulty), is thought to reflect a stress state such that deviations from one's comfort zone are consistent with a discrepancy between actual and desired states (Hockey, 1986; Hockey & Hamilton, 1983). In theory, at the within-person level increases in subjective workload should be associated with increases in effort. Resource allocation theory suggests when a task is perceived to be challenging individuals need to increase one's allocation of effort (Kanfer & Ackerman, 1989). In this way, effort is thought to be proportional to the perceived difficulty of the task (Kukla, 1972) as obstacles require greater efforts to avoid discrepancies (Campion & Lord, 1982; Lord & Hanges, 1987).

To my knowledge, no research has directly examined how changes in estimates of subjective workload (i.e., within-person deviations) relate to changes in effort. Subjective workload, in general, is typically assessed in retrospect using multi-dimensional measures (e.g., NASA TLX; [Hart & Staveland, 1988]) which aggregate subjective experience (e.g., mental demand, temporal demand) and aspects of volition (i.e., effort). Indeed, ratings of temporal demand, albeit at the aggregated between-person level, are typically highly correlated with mental effort (Hart & Staveland, 1988). Similarly related, empirical findings relating subjective experiences of the task and aspects of volition are typically consistent with resource allocation theory.

Maynard and Hakel (1997), in the context of students preparing hypothetical work schedules, provided evidence at the between-person level for the positive association between subjective task complexity and task motivation. Yeo and Neal (2008) using an air traffic control task and a longitudinal design demonstrated increases (i.e., changes) in perceived difficulty, at the within-person level, were associated with increases in subjective cognitive effort. Further, perceived difficulty was found to mediate the relationship between manipulated task demand and effort. Accordingly, the following hypothesis regarding the within-person relationships between subjective workload and effort was examined across performance trials and intervals.

Hypothesis 1: Subjective workload will have a positive effect on effort.

Effect of Effort on Performance

Yeo and Neal's (2008) findings mentioned above reinforce the notion that self-regulation is inherently complex even without considering performance (Kanfer, Ackerman, & Heggestad, 1996). As such, within-person deviations of subjective experience must be accounted for in order to understand the complex dynamic relationships between effort and performance.

Effort intensity, as conceptualized by the magnitude of motivational arousal at a point in time, is volitional and as such can link cognition with action in order to explain meaningful variation in adaptive performance at the within- and between-person levels

(Lord & Levy, 1994). In terms of control system theory, within-person deviations of effort provide an indication of the effector subsystem. Much consideration has been paid to between-person characteristics (e.g., self-efficacy, goals) related to effort (Vancouver, 2005), however, few studies have directly measured effort (Blau, 1993; Brown & Peterson, 1994) and even fewer have examined variations in effort within individuals over time (Schmitz & Skinner, 1993; Yeo & Neal, 2004, 2008). In the few studies that have used longitudinal, multilevel approaches, performance was not the primary outcome variable of interest; rather, variations in effort were predicted from variables of interest such as general mental ability or conscientiousness (Schmitz & Skinner, 1993; Yeo & Neal, 2004, 2008).

In theory, when increased control activity is required one can either withdraw or persist with respect to task-related behavior (Carver & Scheier, 1981). Withdrawal is associated with reduced effort: giving up, resignation to failure, and disengagement from the task (Carver & Scheier, 1981). In contrast, persistence involves changing behavior by way of attentional resource allocation (Kanfer & Ackerman, 1989; Norman & Shallice, 1986), effort mobilization (Wright & Brehm, 1989), or changing the direction of behavior (i.e., employing a different strategy; [Klein, 1989]). In this way, effort either involves increasing the allocation of limited attentional resources or selectively focusing on critical information required to adapt (Lord & Levy, 1994).

When examining the volitional aspects of control, not necessarily accounting for subjective experiences of the task, some researchers on one hand, using a between-person level of analysis, have found self-reported effort or time on task to be positively associated with task performance (Brown & Leigh, 1996; Rasch & Tosi, 1992; Terborg & Miller, 1978). On the other hand, Schmitz and Skinner (1993) using time-series analysis involving children's cognitive performance in the classroom, did not find a positive relationship between effort and performance. Contrary to their expectations, there was not a consistent within-person effect. Thus, perhaps more complex relationships better explain the processes involved in self-regulation.

Yeo and Neal (2008) found effort to have a dynamic relationship with performance, after controlling for perceived difficulty, as a function of the level of task demand and shifts involved. Specifically, during overall low and stable task demand higher effort scores were related to higher performance (Study 1). Similarly, during overall high but stable task demand effort was positively related to performance (Study 2, Phase 1). In contrast, during overall high task demand coupled with shifts, effort was not a significant predictor of performance (Study 2, Phase 2). Taken together, effort typically has a positive direct effect on performance, but this positive effect may be contingent upon when the relationship is tested with respect to the duration of performance following a shift. Accordingly, the following hypothesis regarding effort and performance was examined across performance trials and intervals.

Hypothesis 2: Effort will have a positive effect on performance controlling for subjective workload.

In a section below on the *Breakdown in the Control Process*, I further consider how the effort-performance relationship might be contingent upon the duration of performance following an increase in task demand.

Indirect Effect of Subjective Workload on Performance through Effort

The role of self-regulation with respect to performance is complex (Kanfer et al., 1996). Yet, when trying to represent the self-regulatory cycle, insufficient consideration has been given to how the interplay between subsystem indicators (i.e., subjective workload, effort) explain performance (Vancouver, 2005). This lack of understanding is especially salient in relation to shifts in task demand and performance duration in general.

A deviation from a desired or referent standard as reflected in an increase in subjective workload is thought to signal a need to better regulate attention to a task, and effort intensity, as conceptualized by the magnitude of motivational arousal at a point in time, is needed for performance to be stabilized (Lord & Levy, 1994). Not only must an individual be aware of a disturbance, he or she must have the will to address it.

From a cognitive-energetic perspective, the argument for a positive relationship between subjective workload and performance following shifts in task demand (Hockey, 1997) is likely by way of increases in effort. Specifically, an elevated level of subjective workload immediately after a shift (increase or decrease) in task demand has been posited as reflecting active coping by way of an increase in the allocation of cognitive resources (Hockey, 1997). More specific to an increase in task demand, an increase in energetic arousal, indicating an increase in cognitive resources can result from a shift to higher levels of task demand (Helton, Shaw, Warm, Matthews, & Hancock, 2008). In this way, higher than typical levels of subjective workload are thought to be positively associated with performance (Hockey, 1986), however, increases in subjective workload result in an appropriate state of control if individuals are increasing effort to counteract the increase.

Put another way, changes in subjective workload indicate a disturbance in the system and the allocation of cognitive resources via increases in effort are needed to bridge current and desired levels of performance (Yeo & Neal, 2008). That is, subjective workload indirectly influences performance through the positive subjective workload-effort and effort-performance relationships. Accordingly, the following hypothesis was examined across performance trials and intervals.

Hypothesis 3: Subjective workload will have a positive indirect effect on performance through effort.

Direct Effect of Subjective Workload on Performance

Given changes in subjective experience are more dependent on the task whereas the expenditure of effort is a more internal controllable factor, these constructs although positively related to one another likely engender different effects on performance (Freude & Ullsperger, 2000; Klein, 1989; Wickens, Gordon, & Liu, 1998). Effort is typically positively related to performance after controlling for subjective experiences (Yeo & Neal, 2008), however, the direct effect of subjective workload on performance is often characterized by inconsistent results (i.e., dissociation; [Yeh & Wickens, 1988]) showing a range of negative, positive, and null effects (Cumming & Croft, 1973; Goldberg & Stewart, 1980; Matthews, 1986; Moroney, Biers, & Eggemeier, 1995; Mracek et al., 2014). More specifically, research examining subjective workload in unstable environments (e.g., following a shift[s] in task demand) has predominantly focused on the subjective workload-performance relationship at the between-person level, although the conclusions drawn tend to reflect a within-person phenomenon (Cox-Fuenzalida, 2007; Hancock, Williams, & Manning, 1995). In this way, changes in subjective workload have been implicated as an important part of the adaptation process, however its role is not clear.

The inconsistent direct effect of subjective workload on performance following shifts in task demand highlights the need to account for the volitional aspect of self-regulation (i.e., effort effects on performance). In this way, after controlling for effort subjective workload should be negatively related to performance. On one hand, without accounting for increases in effort higher levels of subjective workload can potentially reflect active coping by way of increases in the allocation of cognitive resources (Hockey, 1997). On the other hand, when controlling for effort (i.e., increases in the allocation of resources), increases in subjective workload likely represent capabilities being exceeded. As such, consistent with the definition of the construct, changes in subjective workload reflect a disturbance in the control system congruent with a transitional state, such as overload. In addition, subjective workload's relationship with performance depends on the nature of the shift in task demand and the duration of performance following a shift.

Using a longitudinal, multilevel approach Mracek et al. (2014) found deviations in subjective workload immediately following an increase in task demand were typically negatively related to performance, whereas following decreases nonsignificant relationships were observed. Also, using a longitudinal, multilevel approach Yeo and Neal (2008) found perceived difficulty, at the within-person level, to have a dynamic relationship with performance as a function of the level of task demand involved. Specifically, during overall low and stable task demand perceived difficulty was not related to performance (Study 1). In contrast, during overall high but stable task demand perceived difficulty was negatively related to performance (Study 2, Phase 1). Similarly, during overall high task demand coupled with shifts perceived difficulty was negatively related to performance (Study 2, Phase 2). Taken together, given the conceptual similarity to perceived difficulty, subjective workload should be negatively related to performance. Accordingly, the following hypotheses regarding the relationship between subjective workload and performance following a shift in task demand was examined across performance trials and intervals.

Hypothesis 4: Subjective workload will have a negative direct effect on performance controlling for effort.

In theory, decreases in task demand can result in states of underload as reflected in negative subjective workload-performance relationships (Hancock & Warm, 1989;

Hockey, 1997). For example, during vigilance tasks a decrease can result in individuals experiencing task-requirements outside of one's region of comfort (See, Howe, Warm, & Dember, 1995). However, when tasks involve complex decision making and problem-solving as compared to more sensory or vigilance tasks, decreases in task demand likely do not result in task requirements outside of one's region of comfort. From a task complexity perspective (Wood, 1986), knowledge and skill requirements in relation to the required activities and events for tasks which involve complex decision making and problem-solving are inherently higher compared to more sensory or vigilance tasks. It is likely the timing, frequency, and location requirements for more complex tasks even following decreases in task demand results in a considerable level of required attentional resources. Resources are needed to process information cues, execute distinct acts, and coordinate inputs and products such that a state of underload is not likely. In this way, negative subjective workload-performance relationships following decreases in task demand are unlikely (Mracek et al., 2014). Accordingly, the following hypothesis was examined in performance trials involving a decrease in task demand.

> *Hypothesis 5:* The nature of the shift in task demand will moderate the negative subjective workload-performance direct effect such that the relationship will become smaller following a decrease in task demand.

Breakdown in the Control Process

I propose variability in the relationship between effort and performance (e.g., Yeo & Neal, 2008), after accounting for variations in subjective workload, can be better explained by considering the nature of the information-processing demands in relation to not only shifts in task demand but also the duration of performance following shifts. Specifically, the relationship between effort and performance following a decrease in task demand likely does not vary as a function of the duration of performance (i.e., immediate vs. downstream intervals). In contrast, more downstream from increases in task demand the nature of the relationship between effort and performance changes in relation to the relationship immediately following an increase. Specifically, more downstream from an increase in task demand, increases in effort will not be as strongly related to performance.

On one hand, the subjective experience of trying hard (Porter & Lawler, 1968; Vroom, 1964) immediately following an increase in task demand is positively related to performance such that effort is thought to positively influence the speed of information processing (Humphreys & Revelle, 1984; Kahneman, 1973). On the other hand, increases in effort are related to performance up to a limit (Norman & Bobrow, 1975). If individuals do not allocate resources commensurate with the changes in performance requirements immediately following an increase, then more downstream, either increasing the allocation of limited attentional resources or selectively focusing on critical information required to adapt, will not likely be able to compensate for the unresolved task demands. In this way, limits of processing resources are more likely to be met more downstream from increases as reflected in the reduction of the positive relationship between effort and performance. From an empirical perspective, Yeo and Neal (2008) found effort was typically positively related to performance, however when task demands involved shifts, effort was not a significant predictor of performance (Study 2, Phase 2). I argue the performance duration following a shift in task demand (i.e., immediate vs. downstream performance periods) is important to understanding when effort will or will not have an effect on performance. Accordingly, the following hypothesis regarding effort and performance was examined in performance trials involving an increase in task demand.

> *Hypothesis 6*: The nature of the shift in task demand and duration of performance following such shifts will moderate the positive relationship between effort and performance such that the positive relationship will become smaller downstream after an increase in task demand.

Total Effects of Subjective Workload Moderated by Shifts and Performance Duration

The demonstrated aftereffects of stress on performance (Cohen, 1980) highlights the importance of examining the effects of subjective workload downstream following changes in task requirements. In particular, changes in subjective workload taking place more downstream from an increase in task demand provide an indication of how well individuals are keeping up with the consequences of earlier experiences as the effects of stressors are more likely to appear after the individual has encountered the increase in task demand for some time (Hockey, 1984). From a resource allocation perspective, processing resources are limited such that during an increase in task demand eventually individuals will experience a deterioration of performance (Norman & Bobrow, 1975). In this way, the overload of processes results in a gradual deterioration of task performance as opposed to a precipitous failure (Norman & Bobrow, 1975). Likewise from a cognitive-energetic perspective, over a period of performance costs can accumulate, resulting in an unfavorable transition state marked by a depletion of resources (Hockey, 1997).

Mracek et al. (2014) demonstrated the relationship between subjective workload and performance varied across periods of performance in relation to the duration of performance. That is, relationships varied as a function of when they were examined in relation to immediate versus more downstream intervals. Specifically, increases in subjective workload were more strongly and negatively related to performance more downstream following increases in task demand. In contrast, the level of resources available was hypothesized not to be adversely affected downstream from decreases in task demand, such that increases in subjective workload would not represent exceeded capabilities (Cox-Fuenzalida, 2007). However, instead of finding the hypothesized positive relationship, Mracek et al. (2014) found a nonsignificant relationship between subjective workload and performance (See et al., 1995).

With respect to the total effect of subjective workload on performance, the direct negative effect of subjective workload on performance after increases in task demand strengthens in downstream performance intervals, while the indirect positive effect of subjective workload on performance through effort weakens, due to the breakdown in the effort-performance relationship (i.e., Hypothesis 6). Accordingly, the following hypothesis regarding the total effect of subjective workload on performance was examined in performance trials involving an increase in task demand.

> *Hypothesis 7*: The total effects of subjective workload to performance will be moderated by the nature of the shift and duration of performance such that the overall relationship will become negative downstream after an increase in task demand.

It is again important to note that Mracek et al. (2014) confounded the examination of immediate and downstream effects with shifts in task demand such that a shift in task demand was temporary and followed by a subsequent shift in the opposite direction. With this confounding in mind, one could argue that the negative within-person effects of subjective workload on performance observed following an increase in task demand was more a function of the immediate experience of a decrease in task demand as opposed to the preceding experience of an increase. In the present study, for each trial involving a shift, participants received either an increase or a decrease in task demand, which was sustained during the remaining performance intervals of the trial. This allowed me to examine if any increase in the subjective workload-performance relationships are in fact due to capabilities being exceeded following an increase in task demand and not problems during a subsequent decrease in task demand.

Method

Participants

One-hundred and ninety eight undergraduates (mean age = 18.85, *SD* = 1.66; 55% male), from the University of Oklahoma participated for credit toward a psychology course research requirement. The study was conducted in 3-hr sessions with a maximum of 5 participants in each session. Data for 17 participants were removed from analysis due to hardware problems or participants not following instructions.

Performance Task

Participants were decision makers in a computer-based command-and-control peacekeeping environment created using the distributed dynamic decision-making (DDD) simulation software package (Aptima, 2007). Figure 2 provides a picture of the two dimensional map displayed on the monitor with an information panel on the left side. Participants engaged the environment using both buttons of a two-button mouse, controlling three types of units to maintain "influence" in a fictional foreign region of responsibility populated with locals that see the participant units as either friendly or hostile. Participant-controlled units and locals are depicted on the map with different icons (e.g., soldier, medic, tech support). By offering different kinds of aid, hostile locals could be persuaded to consider the participant-controlled units as friendly. A participant's level of influence increased over the region of responsibility by keeping a restricted zone free (shaded, central region of the map) of hostile locals. Locals appeared in random locations on the perimeter of the map and then moved toward the restricted zone. If hostile locals reached the restricted zone, a participant's level of influence decreased (1 point per s per hostile local). The left-side panel displayed information regarding the capabilities and status of selected units and locals as well as the participant's influence and persuasion scores.

The performance environment reflected an open-loop system involving continuous changes in stimuli with no definitive endpoint signaling task completion. The task was cognitively demanding, involved time pressure, and allowed for changes in performance over time. Four interdependent subtasks comprised the peacekeeping game: (1) detecting (searching for) locals, (2) distinguishing between friendly and hostile locals, (3) arranging units to persuade hostile locals, and (4) persuading hostile locals. Participants selected their units and identified locals using the left mouse button, and arranged their units and persuaded locals using the right mouse button. In general, the task was designed to be fairly overwhelming. In past research, scores decrease over the course of a trial (Mracek et al., 2014).

Participant-controlled units

Participants controlled the movements and actions of six units. There were three different types of participant-controlled units; two of each were assigned to the participant: (1) a soldier represented by a soldier icon, (2) a medic represented by a jeep icon, and (3) a tech support represented by a helicopter icon. Each type of unit had the same general capabilities, but they differed on two characteristics: effectiveness of the persuade capability and speed of movement. Table 1 shows each unit's characteristics.

Computer-controlled units

Locals were represented by one of three icons (i.e., soldier, jeep, and helicopter). The purpose of including friendly locals was to increase task demand by diverting participant attention from hostile locals. In this way, friendly locals served as distracters, which do not directly affect influence scores. Locals moved at a slower rate compared to the participant-controlled units and had no capabilities (e.g., a hostile local could not persuade a friendly local to become hostile). Once a local was persuaded or it reached the center of the restricted zone, that local disappeared from the map.

Performance Score

Influence and persuasion scores were displayed on the participants monitor, however, the participants were instructed to consider the influence score to be the primary performance score. Nevertheless, although the persuasion score was not examined in statistical analyses, the participant's effectiveness at persuading hostile locals had an indirect effect on the influence score, such that fully persuading hostile locals would remove hostile units from the restricted zone. The influence score started at 1000 and either increased or decreased. The influence score increased by 1 point per s if the restricted zone did not consist of any hostile locals. By contrast, the influence score decreased by 1 point per s per hostile local in the restricted zone. In the event that only one hostile local was in the restricted zone, the influence score neither increased nor decreased, but remained the same.

Procedures

Figure 3 details the study protocol. At the onset of participation, participants were told that the purpose of this study was to examine how different people learn to perform new and challenging tasks. After a training presentation, participants performed a 5-min practice trial to familiarize themselves with the performance environment and single-item measures. Following the 5-min practice trial, participants performed in a 10-min practice trial. Following the practice trial, participants performed five test trials (each 10 min). All trials were paused every min and the participants indicated (a) the level of workload they were experiencing and (b) the level of effort they were exerting. Previous research involving this pause-and-assess approach has been shown not to be intrusive or disruptive to participants' performance (Endsley, 1995; Mracek et al., 2014; Yeo & Neal, 2004, 2008).

Manipulation of Task Demand

Trials 1, 3, 5 were similar to the practice trial in terms of the behavior of the locals and were used to compare effects with the trials that involved a shift in task demand. These trials involved "stable" task demand to where participants encountered three new friendly and three new hostile locals per minute. In this way, one might also consider Trials 1, 3, and 5 to reflect "routine" task demands as they represent the typical level of task demand encountered across most performance trials and intervals.

Trials 2 and 4 were counterbalanced trials that involved a shift in task demand. Participants were randomly assigned to one of two conditions (Trial 2 increase/Trial 4 decrease, or Trial 2 decrease/Trial 4 increase). During Trials 2 and 4, task demands started at the level of task demand as that represented in Trials 1, 3, and 5 but then after the 5-min mark demands either increased or decreased. During the remaining five performance intervals, task demand was manipulated by varying the number of locals within the region of responsibility, depending on whether there was an increase (i.e., five new friendly and five hostile locals) or decrease (i.e., one and one) as compared to the "stable" or "routine" task demands (i.e., three and three). In all cases, it took a local 2 min to move from the perimeter of the region to the center of the restricted zone. No special instructions regarding these shifts were provided at any time before or during the trials. Table 2 shows the potential number of locals within the region of responsibility during each minute for routine (1, 3, and 5) and shift (2 and 4) trials.

Immediate Versus Downstream Effects

Consistent with Mracek et al. (2014) immediate performance was operationalized as 2-min immediately following a shift (i.e., min 7), and the direct and indirect effect of subjective workload at this particular interval was examined. Downstream performance was operationalized as 4-min following when a shift in task demand began (i.e., min 9), and the effect of subjective workload at this particular mark was examined.

Self-report Measures

Subjective Workload

A single-item subjective workload measure adapted from previous research was used (Grech et al., 2009). The item reads "Mark the level of workload you were experiencing just before the screen froze." Participants responded to this item using a nine-point scale: 1 (*Little to do; little demands*); 3 (*Active involvement required, but easy to keep up*); 5 (*Challenging, but manageable*); 7 (*Extremely busy, barely able to keep up*); 9 (*Too much to do; overloaded; postponing some tasks*). Previous research supported the validity of the single-item measure (Mracek et al., 2014). Specifically, scores on the single-item measure were: (a) sensitive to increases and decreases in objective task demand, (b) strongly correlated with scores on the NASA TLX, and (c) more predictive of performance then scores on the NASA TLX.

Effort

A single-item effort measure from previous research was used (Yeo & Neal, 2004; Yeo & Neal, 2008). The item reads "How hard were you trying just before the screen froze?" Participants responded to this item using a nine-point scale: 1 (*not at all*) to 9 (*extremely hard*). Yeo and Neal (2008) provided validation evidence regarding this single-item measure of effort.

NASA Task Load Index (TLX)

A 6-item 6-dimension workload measure, from Hart and Staveland (1988), was used to assess the multi-dimensional nature of subjective workload in order to provide validation support for the single-item measures of subjective workload and effort. The six dimensions are: mental demand, physical demand, temporal demand, performance, effort, and frustration level. Participants responded to the items after each trial on a 10-point scale ranging for *Low* (1) to *High* (10), with the exception of the performance dimension which ranged from *Good* (1) to *Poor* (10). After the final administration of the NASA-TLX, participants completed a paired comparison of the six dimensions in which they chose the dimension more relevant to their experience. The results of the paired comparison provide weights for each dimension and the overall estimate was determined by adding the six weighted dimension scores together. As evidence for the validity of the single-item measure of subjective workload, correlations between the scores obtained from the single-item measure of subjective workload with scores from the NASA TLX taken immediately after every trial ranged from .54 to .67 (ps $< .01$).

Model Building Procedures

Hypotheses concerning how subjective workload and effort are related to performance were examined using hierarchical linear modeling (HLM). HLM analyses were conducted using maximum likelihood estimation. First, HLMs involving subjective workload as the predictor and effort as the outcome were examined for each performance trial to test Hypothesis 1. Second, HLMs involving both subjective workload and effort as predictors and performance as the outcome were used to test Hypotheses 2, 4, 5, and 6. Third, multilevel indirect effects were modeled to investigate Hypotheses 3 and 7.

A model building approach utilizing the guidelines of Bliese and Ployhart (2002) was followed to determine the appropriate direct effects. In general, a nested model was compared to see if the increase in model complexity improved fit enough with respect to the additional parameters estimated. Specifically, supportive evidence favoring the more complex model was determined via an improvement in the Bayesion information criterion (BIC) equal to or greater than 3 (O'Connell & McCoach, 2008; Raftery, 1995). This principle of parsimony was used throughout this model building approach.

My approach to model building consisted of five steps (Bliese & Ployhart, 2002). The first step involved running an intercepts only model in order to estimate the intra-class correlation coefficient (ICC1), which reflects the between-person variation apart from the within-person variation. Step 2 involved determining the best fitting trajectory of the dependent variable. Linear, quadratic, and cubic trends were tested and the appropriate fixed effects were determined. Step 3 assessed whether trajectory parameters (e.g., linear, quadratic) varied significantly across people or not, however, random effects were excluded from the final model because the models did not converge.

Step 4 involved testing Level-1 predictors and variables representing the reintroduction of the subtracted means of the time-varying variables (i.e., the between-person effect). Single-item assessments from each performance trial were used to create a person-mean centered variable (i.e., centered within context; [Kreft & De Leeuw, 1998]). The mean of subjective workload (Level-2 subjective workload; i.e., between-person subjective workload) and the mean of effort (Level-2 effort; i.e., between-person effort) throughout the performance trial were grand-mean centered.

Step 4 consisted of two sub-steps. Within- and between-person main effects of subjective workload were tested followed by an examination of the within-person subjective workload's interactions with the trajectory variables (e.g., linear performance × within-person subjective workload). Next, while controlling for the significant effects of subjective workload determined in the preceding step, within- and between-person effort main effects of effort were tested followed by an examination of the within-person effect of effort's interactions with the trajectory variables. Step 5 involved assessing alternative Level-1 error structures. Because random effects did not converge in Step 3, an unstructured covariance structure including only the Level-1 (i.e., residual variance [σ^2]) and Level-2 (i.e., intercept [τ_{00}]) variance was used.

Multilevel indirect effects were tested based on the principles put forth by Zhang, Zyphur, and Preacher (2009). Specifically, multilevel tests of indirect effects were examined based on 1-1-1 models (i.e., subjective workload, effort, and performance were measured at the individual level, but Level-1 units [repeated measurements] were nested in Level-2 units [individuals]). The approach described in the preceding paragraph of centering within the context of the trial and reintroducing the mean of each individual's scores across intervals in the Level-2 equation allows for the differentiation of the within-person indirect effect from the between-person indirect effect (Zhang et. al., 2009). Nevertheless, in all the respective models, within-person deviations (Level-1 variable) of effort are considered the link between increases in subjective workload (i.e., within-person subjective workload) and performance.

The Monte Carlo Method for Assessing Mediation (MCMAM) was used to generate a 95% confidence interval (CI) for the within-person indirect effect using 20,000 repetitions. A null hypothesis of no significant indirect effect was rejected when zero fell outside of the CI (Selig & Preacher, 2008). MCMAM is a method used in the multilevel context for assessing models with a level 1 predictor, a level 1 mediating variable, and a level 1 outcome (Preacher & Selig, 2010) and provides better estimates than the conventional Sobel test (Selig & Preacher, 2008).

Results

Table 3 shows the means, standard deviations, and correlations between scores of subjective workload, effort, and performance at the between-person level for all performance trials. As expected, higher levels of subjective workload were associated with higher levels of effort (rs from .75 to .82, $p < .01$). Additionally, subjective workload (rs from –.35 to –.49, $p < .01$) and effort (rs from –.20 to –.42, $p < .01$) yielded negative correlations with performance.

Tables 4 and 5 show the means, standard deviations, and correlations between scores of subjective workload, effort, and performance at the within-person level for trials that involved stable demands and shifts in task demand, respectively. Changes in subjective workload were related to changes in effort (*r*s from .75 to .89, $p < .01$), in addition, increases in subjective workload (*r*s from –.39 to –.57, $p < .01$) and effort (*r*s from –.26 to –.45, $p < .01$) were associated with lower levels of performance.

Figures 4, 5, and 6 display the means of subjective workload and effort across trials characterized by stable, an increase, and a decrease in task demands, respectively. The single-item measures were sensitive to the task demands encountered. Specifically, for trials characterized by stable task demands, subjective workload and effort steadily increased during each performance trial, but decreased across trials (i.e., Trial 5 vs. Trial 1). Trials involving an increase in task demand reflected higher levels of subjective workload and effort in relation to trials involving stable task demands. Further, trials involving a decrease yielded inverted-U trends such that subjective workload and effort increased initially and then decreased following the shift in task demand.

Figures 7 and 8 show the means of performance across trials represented by stable demands and either an increase or decrease in task demand, respectively. During trials characterized by stable task demands, performance scores showed an inverted-U trend within trials, but scores overall increased across trials (i.e., Trial 5 vs. Trial 1). Similarly, trials involving an increase in task demand showed an inverted-U trend within trials, but the decrease in later intervals was stronger, yielding a substantially greater decline in performance and ultimately lower overall scores. Trials involving a decrease in task demand reflected a cubic function. For these trials, scores initially increased, then decreased, and then increased again ultimately leading to higher overall scores.

Subjective Workload → Effort

Hypothesis 1 stated that subjective workload will have a positive effect on effort. Results supported Hypothesis 1 for all seven HLMs examined (Trials 1, 3, and 5 [stable demands]; Trials 2 and 4 [task demand shift]). As shown in Tables 6 and 7, the relationship between subjective workload and effort at the within-person level (see the rows for the "WP SWL" fixed effect) was consistent for trials that involved stable demands (*b*s from .70 to .73, *p*s < .01) and trials that involved an increase or decrease in task demands (*b*s from .63 to .92, *p*s < .01). As shown in Table 7, for Trial 4 when a decrease in task demand was involved, the within-person effect of subjective workload interacted with both the linear ($b = –.13$, $p < .05$) and quadratic effort trajectories ($b = .01$, $p < .01$). Specifically, the positive effect of subjective workload on effort weakened across the intervals but this weakening effect was offset in later intervals. Overall, the results showed consistent support for Hypothesis 1.

Effort → Performance

Hypothesis 2 stated that effort will have a positive effect on performance controlling for subjective workload. Results supported Hypothesis 2 for five out of seven HLMs examined. As shown in Table 8 (see the rows for the “WP EFF” fixed effect) and in support of Hypothesis 2, for trials characterized by stable task demands, within-person effort was positively related to performance (*b*s from 23.56 to 40.07, *p*s < .01). As displayed in Table 9 and in support of Hypothesis 2, when an increase in task demand occurred midway through the trial, within-person effort was again positively related to performance (Trial 2, $b = 18.19$; Trial 4, $b = 52.58$; *p*s < .01). Figure 9 (see panels on the right) illustrates the within-person effects of effort for trials that involved an increase in task demand.

For trials that involved a decrease in task demand the results did not support Hypothesis 2. Within-person effort was again positively related to performance (Trial 2, $b = 25.82$ $p < .05$; Trial 4, $b = 39.85$, $p < .01$). However, as shown in Table 10 and in contrast with Hypothesis 2, the within-person effects interacted with the linear performance trajectory (Trial 2, $b = –6.33$, $p < .01$; Trial 4, $b = –8.65$ $p < .01$) such that the positive effect of effort not only weakened across performance intervals but became negative and significant at the downstream (i.e., min 9) interval (Trial 2, $b = –24.79$, $p < .05$; Trial 4, $b = –29.31$ $p < .01$). Figure 10 (see panels on the right) illustrates this interaction between the performance trajectories and within-person effort during trials that involved a decrease in task demand. This interaction is discussed further in the section below regarding *Dynamic Effects*. Overall, the results showed mixed support for Hypothesis 2, effort was positively related to performance controlling for subjective workload for trials represented by stable demands and an increase in task demands.

However, for trials that involved a decrease in task demands, results did not support a positive effort-performance relationship.

Indirect Effect of Subjective Workload on Performance

Hypothesis 3 stated that subjective workload will have a positive indirect effect on performance through effort. Results supported Hypothesis 3 for five out of seven HLMs examined. In terms of the multilevel indirect effects, increases in subjective workload (i.e., within-person subjective workload) were related to *increases* in effort for trials that involved stable task demands (*b*s from .79 to .81, *p*s < .01). As shown in Table 11 and in support of Hypothesis 3, the indirect effects of subjective workload on performance through effort were again positive and significant (*b*s from 19.06 to 31.61; Sobel's *z*s from 5.01 to 8.33, *p*s < .01).

When trials involved an increase in task demand, increases in subjective workload (i.e., within-person subjective workload) were again related to *increases* in effort (*b*s from .74 to .82, $p < .01$). As shown in Table 12 and in support of Hypothesis 3, again the indirect effect of subjective workload on performance through effort was positive and significant for both Trial 2 ($b = 13.44$, $CI_{95\%}$ [5.98, 20.97], Sobel's $z = 3.51$, $p < .01$) and Trial 4 ($b = 42.86$, $CI_{95\%}$ [33.28, 52.47], Sobel's $z = 8.72$, $p < .01$). For trials that involved a decrease in task demand the results did not support Hypothesis 3. Increases in subjective workload (i.e., within-person subjective workload) were again related to *increases* in effort (*b*s from .74 to .79, $p < .01$). The indirect effect of subjective workload on performance through effort again was positive and significant

(Trial 2, b = 20.29, $CI_{95\%}$ [5.97, 21.00], Sobel's z = 1.96, $p < .05$; Trial 4, b = 29.41, $CI_{95\%}$ [14.82, 44.11], Sobel's z = 3.99, $p < .01$). However, as shown in Tables 10 and 13 and in contrast to Hypothesis 3, as a function of significant negative interactions of within-person effort with the linear performance trajectory, the indirect effect was negative at the immediate performance interval following the decrease in task demand (i.e., min 7) for Trial 4 (b = –8.87, $CI_{95\%}$ [–17.22, –.32], Sobel's z = –2.09, $p < .05$) and for Trial 2, albeit nonsignificant (b = –9.54, $CI_{95\%}$ [–19.96, .83], Sobel's z = –1.80, $p < .10$). This trend continued such that the indirect effect was negative and significant at the downstream (i.e., min 9) performance interval for both Trial 2 (b = –19.49, $CI_{95\%}$ [–34.60, –4.35], Sobel's z = –2.53, $p < .05$) and Trial 4 (b = –21.63, $CI_{95\%}$ [–33.76, –9.37], Sobel's z = –3.50, $p < .01$). Figure 10 (see panels on the right) illustrates this interaction between the performance trajectories and within-person effort during trials that involved a decrease in task demand. Overall, the results showed mixed support for Hypothesis 3, on one hand subjective workload had a positive indirect effect on performance through effort for conditions represented by stable demands or an increase in task demands. On another hand, when individuals encountered a decrease in task demands the results showed a negative indirect effect of subjective workload on performance through effort.

Subjective Workload → Performance

Hypothesis 4 stated that subjective workload will have a negative direct effect on performance. Results supported Hypothesis 4 for five out of seven HLMs examined. As shown in Table 8 (see row for the "WP SWL" fixed effect) and in support of

Hypothesis 4, for trials characterized by stable task demands, within-person subjective workload was negatively related to performance (*b*s from –37.24 to –73.81, *p*s < .01). When a decrease in task demand occurred during trials, as displayed in Tables 10 and 13 and in support of Hypothesis 4, within-person subjective workload was again negatively related to performance (Trial 2, *b* = –96.40; Trial 4, *b* = –102.87; *p*s < .01).

For trials that involved an increase in task demand, the results did not support Hypothesis 4. As displayed in Tables 9 and 12 and in support of Hypothesis 4, within-person subjective workload was again negatively related to performance (Trial 2, *b* = –43.62; Trial 4, *b* = –80.33, *p* < .01). However, in contrast to Hypothesis 4, the within-person effect interacted with the linear performance trajectory (Trial 2, *b* = 7.29; Trial 4, *b* = 8.61, *p* < .01) such that the negative and significant effect of subjective workload weakened throughout both trials. Figure 9 (see panels on the left) illustrates this interaction between the performance trajectories and within-person subjective workload during trials that involved an increase in task demand. This interaction is discussed further in the section below regarding *Dynamic Effects*.

In general, the results showed mixed support for Hypothesis 4. On one hand, subjective workload had a negative and significant direct effect on performance for conditions represented by stable demands or a decrease in task demands. On another hand, when individuals encountered an increase in task demands results did not show a negative direct effect of subjective workload on performance. Instead, the negative subjective workload-performance relationship weakened and became nonsignificant.

Dynamic Effects

Hypothesis 5 stated that the nature of the shift in task demand will moderate the negative subjective workload-performance effect such that the relationship will become smaller following decreases in task demand. Indeed, as shown in Tables 10 and 13, within-person effects interacted with both the linear (Trial 2, $b = 23.76$; Trial 4, $b = 23.86$; *p*s < .01) and quadratic (Trials 2 and 4, *b*s = –1.98, *p*s < .01) performance trajectories such that the negative effect of subjective workload weakened across intervals but became stronger (more negative) toward the end. In this way, results showed mixed support for Hypothesis 5. Figure 10 (panels on the left) illustrates the interactions between the performance trajectories and within-person subjective workload during trials that involved a decrease in task demand.

Hypothesis 6 stated the nature of the shift in task demand and duration of performance following such shifts will moderate the positive relationship between effort and performance such that the positive relationship will become smaller downstream after an increase in task demand. Results did not support this hypothesis. Specifically, there were no significant interactions with the trajectory variables that would have reflected a reduction of the positive effect (Trial 2, $b = 1.63$, $p > .05$; Trial 4, $b = 3.2$, $p > .05$).

Hypothesis 7 stated that the total effects of subjective workload on performance will be moderated by the nature of the shift and duration of performance such that the overall relationship will become negative downstream after an increase in task demand.

As shown in Table 12, results did not support this hypothesis. In sharp contrast to Hypothesis 7, within-person subjective workload interacted with the linear performance trajectory such that the negative total effect of subjective workload weakened throughout the trials and became positive downstream from the increase in task demands. Furthermore, as previously mentioned in the section *Effort → Performance*, there were no significant interactions with the trajectory variables that would have reflected a reduction of the positive effect of effort. Taken together, and opposite to what was hypothesized, the total effects of subjective workload on performance were positive in intervals following increases in task demand.

Discussion

The general pattern of results provided mixed support for the proposed model of the interrelationships between indicators of control subsystems as represented in Figure 1. The proposed model reflects a suppression effect (i.e., inconsistent mediation). Suppression occurs when inconsistent indirect and direct effects are observed—in this case, a positive indirect effect and a negative direct effect (MacKinnon, Krull, & Lockwood, 2000). The proposed model was supported by the pattern of results when individuals encountered stable task demands. Specifically, increases in subjective workload were positively related to effort, and in turn increases in effort were positively related to performance (positive indirect effect). Furthermore, increases in subjective workload were negatively related to performance (negative direct effect). Ultimately, the total effects of subjective workload on performance were negative when accounting for the positive indirect effect through effort.

The proposed interplay between subsystem indicators was partially supported by the pattern of results when individuals encountered an increase in task demands. Increases in subjective workload were again positively related to effort, and in turn increases in effort were again positively related to performance (positive indirect effect). However, the effect of effort did not weaken as a function of the duration of performance following an increase. In other words, the results did not provide evidence for a breakdown in the control process in this manner. Furthermore, the results did not support the prediction that increases in subjective workload would be negatively related to performance following increases in task demand (direct effect). Rather, the negative direct effect of subjective workload weakened throughout trials that involved an increase. Overall, and in sharp contrast to what was predicted, positive total effects were observed at both immediate and downstream intervals following increases in task demand.

When individuals encountered a decrease in task demand, the proposed model depicting the interplay between subsystem indicators was not supported. Increases in subjective workload were again positively related to effort; however, this relationship weakened across the trials but then became stronger toward the end. Contrary to the proposed model, increases in effort were not positively related to performance (indirect effect). This resulted in a negative indirect effect of subjective workload on performance, which was opposite of what was predicted. As predicted, increases in subjective workload were negatively related to performance (negative direct effect). However, the negative direct effect of subjective workload on performance became weaker (less negative) following decreases in task demand (Hypothesis 5). Overall, the total effects of subjective workload on performance were negative following decreases in task demand.

Theoretical Implications

The proposed discrepancy-reducing control framework is thought to be relevant when there is a threat (i.e., disturbance) toward maintaining a favorable internal environment. The present study—using a task that involved complex decision making and problem-solving—lent support to this notion. In particular, in could be inferred that disturbances (i.e., stress) in the control system were likely to occur when the external environment was characterized by the need for sustained attention, such as when encountering overall high stable task demands, or when greater attention is needed (increase in task demand). In contrast, the expected interrelationships between parameters of the subsystem indicators did not occur when individuals encountered a decrease in task demand.

Direct effect

In terms of cognitive-energetic theory, an elevated level of subjective workload immediately after either a *decrease* or *increase* in task demand has been proposed to reflect active coping by way of an increase in the allocation of cognitive resources

(Hockey, 1997). When examining trials that involved a decrease in task demand, higher than typical levels of subjective workload were not positively associated with performance as a function of either direct or indirect effects. This finding is not consistent with previous research (Mracek et al., 2014) such that in this previous study, a decrease in task demand was associated with a nonsignificant direct effect. In the present study, after decreases in task demand increases in subjective workload were associated with decreases in performance. However, considering that performance was increasing in later intervals, this relationship does not suggest that task demands were outside of one's region of comfort, requiring increases in the allocation of cognitive resources (i.e., effort). Rather, this relationship more likely reflects that individuals were increasing control activity when it should not have been needed. Though the direct effect became less negative, nevertheless, negative direct effects were observed.

When examining performance intervals that involved an increase in task demand—where the performance trajectory was characterized by gradual and then a more pronounced deterioration in performance—results indicated that higher than typical levels of subjective workload during these performance intervals were not as negatively related to performance compared to the relationships observed earlier in the performance trials. This particular finding is in sharp contrast with Mracek et al. (2014) who showed that negative within-person subjective workload effects on performance, which were thought to reflect capabilities being exceeded, were more likely to occur in downstream intervals following increases in task demand as opposed to intervals immediately following increases. Considering in Mracek et al. (2014) increases in task demand were followed by subsequent decreases in task demand (i.e., multiple shifts in task demand), the effects observed during the operationalization of downstream effects of an increase may have reflected immediate effects of decreases in task demand. In this way, individuals were likely increasing control activity when it should not have been needed.

A different explanation with respect to the aforementioned study is that environments characterized by *multiple* shifts in task demand are more likely to induce disturbances (i.e., stress) as a function of the duration of performance following the more *continuous* fluctuation of task demand. Stronger subjective workload-performance relationships following multiple shifts in task demand suggest that such conditions are inherently more stress inducing. In this way, individuals may be especially sensitive to external environments characterized by instability such as when encountering multiple changes in task demands (e.g., stable-decrease-increase) more so than environments characterized by a single sustained shift in task demand. Effects observed in downstream performance intervals may represent capabilities being challenged in terms of the repeating self-regulatory process of perceiving, comparing, and effecting in relation to changes in the need of attentional resources to process information cues, execute distinct acts, and coordinate inputs and products. That is, perceptions of workload should be proportional to objective task demands and in turn effort should be commensurate with perceptions of workload. The self-regulatory process of perceiving, comparing, and effecting is thought to repeat until a disturbance is resolved.

The results of Mracek et al. (2014), in particular the negative direct effect of subjective workload on performance downstream from increases in task demand, suggests the self-regulatory process of perceiving, comparing, and effecting is taxing. In this way, after a greater duration of performance involving *multiple* shifts, individuals are sensitive (i.e., more likely to experience a disturbance in the control system) to increases in task demand thus reflecting negative subjective workload-performance relationships as opposed to the present study where following a single sustained increase in task demand the relationship became less negative as a function of the duration of performance following the shift.

The present study suggests different control states can be inferred from subjective workload-effort-performance relationships in relation to the duration of performance. Reporting a discrepancy between actual and desired states before an increase in task demands reflects an inappropriate control state such that although the use of control may be required, as reflected in the significant interrelationships between the subsystem indicators, individuals may lack the necessary capability to handle task demands in order to achieve a less undesirable cognitive state (Hockey, 1986). That is, perhaps performance (i.e., output) was potentially adversely affected more downstream because a mismatch remained unresolved and the need for continued control activity persisted; however, individuals did not (or could not because of a limit of skill capability) increase their control activity relative to earlier in the performance trial. In contrast, increases in subjective workload were less negatively related to performance downstream from an increase in task demands—as compared to the relationship examined in earlier performance intervals— this reflects a striving, effortful control state appropriate in relation to the duration of performance following the change in task demands. Put another way, higher than typical levels of subjective workload engendered an appropriate state of control if individuals were increasing effort to coincide with an increase in task demands.

For the present study, in terms of resource allocation theory, the extent of the obstacle with respect to an increase in task demand, was thought to be commensurate with the duration of the task following the change in task demand. The present study suggests the self-regulatory process of perceiving, comparing, and effecting, was more adaptive when the control activity corresponded with the increase in task demand. That is, adaptive performance at the within-person level was characterized by the appropriate utilization of control processes in relation to the change in task demand. Results suggest stress served to focus attention, in turn, goal striving was made salient (Karoly, 1993). Put another way, individuals that perceived a relatively greater need to self-regulate in downstream intervals performed better compared to their counterparts that experienced a relatively greater need to self-regulate leading up to or immediately following an increase in task demand.

The positive total effect of subjective workload on performance (i.e., within-person) in downstream performance intervals needs to be considered with respect to the negative between-person effect (average level of subjective workload across the performance trial) representing relatively stable differences in characteristic patterns of cognitive activity when responding to stress (Mracek et al., 2014). Given the opposite direction of effects depending on the level of analysis, these findings underscore the importance of using longitudinal, multilevel approaches for disaggregating (Curran & Bauer, 2011) within-person (i.e., state) and between-person (i.e., trait) components. In particular, increases in subjective workload can represent an appropriate control state, however average levels throughout a performance episode are negatively related to adaptability.

The present study's findings underscore the importance of examining dynamic subjective workload-performance relationships in relation to not only the objective information-processing demands, but also the duration of performance following shifts in task demand. Furthermore, these findings taken in conjunction with the findings of Mracek et al. (2014) suggest the extent of the stability in the task environment (i.e., multiple shifts vs. a single sustained shift) influences adaptability such that researchers need to consider the *number* of shifts in task demand *within* a performance episode, in addition to (a) the *direction* of shifts (i.e., increase vs. decrease), and also (b) the *duration* of performance following *each* shift (i.e., immediate vs. downstream performance intervals).

The present study's findings taken in conjunction with Yeo and Neal's (2008) findings suggest during overall low and stable task demand increases in subjective workload will not be associated with performance, however, during overall high and stable task demands increases in subjective workload will be negatively related to performance. In contrast, increases in subjective workload following a sustained, single increase in task demands are less negatively related to performance compared to the relationships examined in preceding performance intervals where task demands were stable. In the present study, following decreases in task demands, increases in subjective workload were negatively related to performance. Yeo and Neal (2008) observed a negative relationship between perceived difficulty and performance during overall high task demand coupled with shifts in task demand. One explanation for this finding of Yeo and Neal (2008) is that the changes in task demand were more characteristic of decreases in objective task demand. Or, as explained in the previous paragraph, multiple shifts in task demand provided an obstacle in and of itself such that the duration of performance involving the process of perceiving, comparing, and effecting was taxing resulting in disturbances more likely to be experienced. As such, similar to the findings of Mracek et al. 2014, a change in the relationship between workload (i.e., mismatch between current and desired states) and performance was a function of the need to more frequently adapt with less emphasis being placed on the direction of the objective shift in task demand.

Indirect effect

Positive total effects of subjective workload on performance when considering effort were observed depending on when the relationship was examined. Indeed, results support the notion that an increase in subjective workload signals a need to increase the allocation of cognitive resources vis-a-vis effort when responding to stable or increased task demand. In this way, effort facilitates the coordination of inputs and task products.

The present study's findings taken in conjunction with Yeo and Neal's (2008) findings suggest that during overall low or high stable task demand increases *in effort* will be positively related to performance. In the present study, following a single sustained increase in task demand, increases in effort were a significant and positive predictor of performance. In contrast, following a single sustained decrease in task demand, increases in effort were negatively related to performance. Yeo and Neal (2008) did not observe a relationship between increases in effort and performance during overall high task demand coupled with shifts in task demand. However, in the present study increases in effort typically had a positive effect on performance, but this effect changed depending upon the nature of the shift in task demand. On one hand, effort had a dynamic relationship with performance following decreases in task demand, nevertheless effort was negatively related to performance. On another hand, following an increase in task demand, increases in effort were positively related to performance, and this relationship was not contingent upon when the relationship was tested with respect to the duration of performance following the increase.

Adaptive performance was characterized by a link between cognition and action such that increases in effort were similarly related to performance throughout trials that involved stable and increased task demands. Although not in the manner predicted, a stable relationship supports the notion that increases in effort are related to performance up to a limit (Norman & Bobrow, 1975). If individuals do not allocate resources commensurate with the changes in performance demands immediately following an increase, then more downstream, either increasing the allocation of limited attentional resources or selectively focusing on critical information required to adapt, would not compensate for the unresolved task demands. Put another way, an increase in effort was useful for adapting but not less or more efficacious in relation to the duration of the task following a single sustained increase in task demand.

Limitations and Directions for Future Research

There are several limitations to the present study that are important to acknowledge. First, future research needs to be mindful of the context of the multilevel analysis when investigating the interrelationships between control system indicators. In particular, in the present study and in Mracek et al. (2014), the multilevel effects were couched *within* performance trials, whereas other research typically has looked at the relationships between perceptions of workload (i.e., difficulty) *across* performance trials (e.g., Yeo and Neal, 2004, 2008). This is especially important with respect to centering within context (Kreft & De Leeuw, 1998) such that increases in variables are in relation to either the performance trial—as in the present study—or spanning across a series of performance trials. The context (i.e., within performance trials or spanning performance trials) also influences the trajectory of performance when modeling changes in performance across measurement occasions. Specifically, when examining effects within performance trials the trajectory of performance is typically a function of the inherent nature of the task (e.g., in the present study linear, quadratic, and cubic trajectory parameters were significant). In contrast, when modeling performance across trials the trajectory of performance typically follows a trend reflecting the power law (Newell & Rosenbloom, 1981). Furthermore, in the present study the within- and between-person effects were framed within relatively brief (10 mins) performance trials (i.e., performance episodes). Effects may be different when examined across longer performance trials. Similarly, dynamic effects might be influenced by, if not contingent upon, the particular timing of the shift(s) considering that in the present experiment the shifts in task demands occurred midway through the trials.

Second, related to the first, the operationalization of immediate but more so downstream performance intervals may not have been sensitive enough to capture the hypothesized dynamic effects. Concurrent assessments were measured every 1 min rather than more frequently, such as every 30 s. However, the more frequent the assessments the greater the likelihood task performance would have become disrupted. It should be noted that the significance of the effects did not change if immediate performance was operationalized at the preceding performance interval (i.e., Min 6 instead of Min 7). Similarly, with respect to the operationalization of the downstream interval, effects did not change the pattern of results when examined at the end of the performance trial (i.e., Min 10 instead of Min 9).

With respect to effects in downstream performance intervals, a lengthy performance episode that entails an increase in task demand would be more likely to induce a breakdown in the effort-performance relationship. In this way, in contrast with the present study, following a lengthy sustained increase in task demands more complex dynamic effects would be observed such that the positive effect of effort would become stronger more immediately following an increase (i.e., positive interaction with linear performance), however, later on the influence of increases in effort would reduce or start to weaken (i.e., negative interaction with quadratic performance). Following a lengthy sustained decrease in task demands, perhaps the task would reflect more of a vigilance task such that, the positive effect of effort would weaken more immediately following a decrease as in the present study (i.e., negative interaction with linear performance). However, later on the influence of increases in effort would return to being more positive in nature (i.e., positive interaction with quadratic performance). Put another way, as a function of underload (Hockey, 1986) increases in effort would reflect active coping by way of an increase in the allocation of cognitive resources thus reflecting a positive effort-performance relationship.

Third, future research needs to better disentangle the extent of stability in the performance environment (i.e., multiple shifts in task demand vs. a single sustained shift in task demand) in relation to the direction and duration of the shift in task demand. Research has demonstrated drops in performance following increases or decreases (Cox-Fuenzalida & Angie, 2005; Hancock et al., 1995), however, less is known when multiple shifts involve changes in different directions. Furthermore, future research needs to follow a multilevel approach and account for the volitional aspect of adaptation. Are disturbances in the control system more a function of the objective task demand, duration of performance following a shift in task demand, or the number of shifts in task demand? In particular, future research where multiple shifts in task demand occur need to be compared to conditions involving more sustained shifts while accounting for objective levels of task demand.

Finally, considering the student sample and lab context of this study, it is important to extend this research to more real-world environments that represent contexts to where inefficiencies involved in control processes result in potentially serious consequences. In a more practical setting, a performance trial (i.e., episode) likely spans hours whereby multiple shifts in objective task demands are experienced. Related, more research is needed to compare relationships between control subsystem indicators in tasks characterized by complex decision making and problem-solving in relation to more sensory or vigilance tasks (See, Howe, Warm, & Dember, 1995).

Conclusion

The present study demonstrated relationships underlying control theory are relevant when there is a threat toward maintaining a favorable internal environment. Relationships were examined using a longitudinal, multilevel approach suitable for disaggregating within-person (i.e., state) and between-person (i.e., trait) components. The proposed model reflecting a positive indirect effect and a negative direct effect (i.e., inconsistent mediation) was supported when individuals encountered stable task demands. However, there was little support for inconsistent mediation in trials involving shifts in task demand. Rather, dynamic effects were observed as a function of the shift in task demands such that changes in subjective workload showed increasingly positive effects on performance after increases in task demand but increasingly negative effects after decreases in task demand. Overall, this research helps to clarify the ambiguity regarding the dissociation between subjective workload and performance by accounting for indirect effects such as the volitional aspect of control (i.e., effort) and examining within-person relationships reflecting states of control, in stable as compared to environments characterized by a sustained shift in task demand. More broadly, this approach underscores the importance of using multilevel approaches for testing theory on how individuals as a function of self-regulation respond to stress.

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Table 1

Summary of Unit Characteristics

Units	Icon	Persuade	Speed
Soldier	Soldier	High	Slow
Medic	Jeep	Medium	Medium
Tech Support	Helicopter	Low	Fast

Note. Persuade = unit's speed at persuading hostile locals.
Speed = how fast a unit moves.

Table 2

Person-period Design Matrix

ID	C	T	MIN	FRI	HOS	ID	C	T	MIN	FRI	HOS	ID	C	T	MIN	FRI	HOS
1	1	R	1	3	3	1	1	2	1	3	3	1	1	4	1	3	3
1	1	R	2	3	3	1	1	2	2	3	3	1	1	4	2	3	3
1	1	R	3	3	3	1	1	2	3	3	3	1	1	4	3	3	3
1	1	R	4	3	3	1	1	2	4	3	3	1	1	4	4	3	3
1	1	R	5	3	3	1	1	2	5	3	3	1	1	4	5	3	3
1	1	R	6	3	3	1	1	2	6	**5**	**5**	1	1	4	6	**1**	**1**
1	1	R	7	3	3	1	1	2	7	**5**	**5**	1	1	4	7	**1**	**1**
1	1	R	8	3	3	1	1	2	8	**5**	**5**	1	1	4	8	**1**	**1**
1	1	R	9	3	3	1	1	2	9	**5**	**5**	1	1	4	9	**1**	**1**
1	1	R	10	3	3	1	1	2	10	**5**	**5**	1	1	4	10	**1**	**1**
2	2	R	1	3	3	2	2	2	3	3	3	2	2	4	1	3	3
2	2	R	2	3	3	2	2	2	3	3	3	2	2	4	2	3	3
2	2	R	3	3	3	2	2	2	3	3	3	2	2	4	3	3	3
2	2	R	4	3	3	2	2	2	3	3	3	2	2	4	4	3	3
2	2	R	5	3	3	2	2	2	3	3	3	2	2	4	5	3	3
2	2	R	6	3	3	2	2	2	6	**1**	**1**	2	2	4	6	**5**	**5**
2	2	R	7	3	3	2	2	2	7	**1**	**1**	2	2	4	7	**5**	**5**
2	2	R	8	3	3	2	2	2	8	**1**	**1**	2	2	4	8	**5**	**5**
2	2	R	9	3	3	2	2	2	9	**1**	**1**	2	2	4	9	**5**	**5**
2	2	R	10	3	3	2	2	2	10	**1**	**1**	2	2	4	10	**5**	**5**

Note. ID = Participant ID; C = Condition (1 = increase/decrease; 2 = decrease/increase). T = Trial. R = Routine trial (Trials 1, 3, and 5). FRI = new number of friendly units. HOS = new number of hostile units. MIN = Minute. Bold indicates when task demand manipulation occurs.

Table 3

Means, Standard Deviations, and Correlations for Subjective Workload, Effort, and Performance at the Between-person Level

Variable[a]	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. SWL 1	4.91	1.36	-----														
2. SWL 2[b]	4.42	1.59	.75	-----													
3. SWL 3	4.52	1.57	.77	.82	-----												
4. SWL 4[b]	4.01	1.50	.66	.56	.76	-----											
5. SWL 5	4.14	1.62	.69	.69	.84	.82	-----										
6. EFF 1	5.25	1.67	.69	.54	.52	.45	.46	-----									
7. EFF 2[b]	4.67	1.83	.62	.82	.69	.48	.55	.73	-----								
8. EFF 3	4.63	1.73	.64	.71	.80	.62	.67	.70	.84	-----							
9. EFF 4[b]	4.22	1.78	.58	.53	.65	.76	.66	.63	.66	.80	-----						
10. EFF 5	4.29	1.87	.61	.60	.69	.66	.77	.64	.71	.84	.85	-----					
11. PERF 1	918.91	188.73	–.43	–.38	–.33	–.35	–.31	–.31	–.32	–.28	–.31	–.27	-----				
12. PERF 2[b]	909.87	202.09	–.36	–.49	–.36	–.24	–.27	–.27	–.42	–.31	–.27	–.23	.80	-----			
13. PERF 3	944.23	219.21	–.31	–.35	–.37	–.32	–.29	–.22	–.32	–.29	–.32	–.23	.75	.81	-----		
14. PERF 4[b]	964.57	194.45	–.30	–.23	–.29	–.43	–.32	–.21	–.19	–.20	–.32	–.23	.75	.70	.82	-----	
15. PERF 5	936.06	212.40	–.32	–.34	–.32	–.36	–.35	–.21	–.25	–.21	–.27	–.20	.78	.78	.84	.86	-----

Note. $N = 198$. SWL = subjective workload; EFF = effort; PERF = performance.
[a] Numbers = Trial.
[b] Trial that involved a shift in task demand.
$r > |.15| = p < .05$. $r > |.20| = p < .01$.

Table 4

Means, Standard Deviations, and Correlations at the Within-Person Level for Trials Involving Stable Task Demands

	Trial 1				Trial 3				Trial 5			
Variable	1	2	3	4	1	2	3	4	1	2	3	4
1. PERF	-----				-----				-----			
2. Linear	−.56	-----			−.43	-----			−.38	-----		
3. SWL	−.53	.69	-----		−.45	.62	-----		−.42	.55	-----	
4. EFF	−.43	.56	.80	-----	−.35	.52	.83	-----	−.26	.43	.79	-----
M	918.91	-----	4.91	5.25	944.23	-----	4.52	4.63	936.06	-----	4.14	4.29
SD	319.07	-----	2.33	2.40	320.77	-----	2.36	2.39	309.46	-----	2.27	2.42

Note. $N = 1980$. SWL = subjective workload; EFF = effort; PERF = performance.
$r > |.05| = p < .05$. $r > |.06| = p < .01$.

Table 5

Means, Standard Deviations, and Correlations at the Within-Person Level for Trials Involving a Shift in Task Demand

	Increase in task demand				Decrease in task demand			
Variable	1	2	3	4	1	2	3	4
1. PERF	-----	−.59	−.54	−.40	-----	−.19	−.39	−.31
2. Linear	−.66	-----	.73	.61	−.31	-----	.22	.16
3. SWL	−.57	.81	-----	.87	−.51	.27	-----	.72
4. EFF	−.43	.63	.75	-----	−.45	.20	.89	-----
M^a	854.85	-----	5.02	5.22	966.01	-----	3.81	4.11
SD^a	413.31	-----	2.57	2.51	261.56	-----	2.22	2.39
M^b	911.07	-----	4.39	4.42	1017.00	-----	3.64	4.02
SD^b	379.00	-----	2.62	2.60	237.47	-----	2.11	2.37

Note. SWL = subjective workload; EFF = effort; PERF = performance.
[a] Values below the diagonal reflect the descriptive statistics for Trial 2.
[b] Values above the diagonal reflect the descriptive statistics for Trial 4.
All correlations $p < .01$ (two tailed).

Table 6

Summary of HLM Models Predicting Effort for Trials Involving Stable Task Demands

Fixed Effects	Trial 1	Trial 3	Trial 5
Intercept	5.14 (0.12)**	4.22 (0.11)**	4.11 (0.11)**
Level 1			
Linear effort	–0.02 (0.06)	0.12 (0.03)**	0.04 (0.03)
Quadratic effort	0.02 (0.02)	–0.01 (0.003)†	0.00 (0.00)
Cubic effort	–0.00 (0.00)	NA	NA
WP SWL	0.73 (0.02)**	0.70 (0.02)**	0.73 (0.02)**
Level 2			
BP SWL	0.89 (0.05)**	0.88 (0.05)**	0.89 (0.05)**
Level 1 *df*	1778	1779	1779
Level 2 *df*	196	196	196
ICC (between-person variance)	.42	.47	.55

Note. Intercept reflects effort at Minute 1. Parenthetical values indicate standard errors. NA = parameter not in final model; SWL = subjective workload; WP = within-person; BP = between-person.

† $p < .10$. * $p < .05$. ** $p < .01$ (two tailed).

Table 7

Summary of HLM Models Predicting Effort for Trials Involving a Shift in Task Demand

	Shift in task demand			
	Increase		Decrease	
Fixed effects	Trial 2	Trial 4	Trial 2	Trial 4
Intercept	4.70 (0.20)**	4.12 (0.14)**	4.03(0.11)**	4.07 (0.18)**
Level 1				
Linear effort	0.17 (0.06)**	0.07 (0.02)**	0.04 (0.04)	0.06 (0.06)
Quadratic effort	–0.01 (0.01)	NA	–0.00 (0.00)	–0.01 (0.01)
WP SWL	0.63 (0.04)**	0.74 (0.03)**	0.77 (0.02)**	0.92 (0.06)**
Linear effort × WP SWL	NA	NA	NA	–0.13 (0.03)**
Quadratic effort × WP SWL	NA	NA	NA	0.01 (0.003)**
Level 2				
BP SWL	0.73 (0.10)**	0.96 (0.06)**	1.08 (0.04)**	0.92 (.10)**
Level 1 *df*	897	880	879	895
Level 2 *df*	98	96	96	98
ICC (between-person variance)	.29	.34	.63	.58

Note. Intercept reflects effort at Minute 1. Parenthetical values indicate standard errors. NA = parameter not in final model; SWL = subjective workload; WP = within-person; BP = between-person.
† $p < .10$. * $p < .05$. ** $p < .01$ (two tailed).

Table 8

Summary of HLM Models Predicting Performance for Trials Involving Stable Task Demands

Fixed Effects	Trial 1	Trial 3	Trial 5
Intercept	955.06 (19.67)**	961.30 (22.14)**	899.13 (20.46)**
Level 1			
Linear performance	157.74 (11.40)**	101.92 (12.80)**	112.28 (12.35)**
Quadratic performance	−41.79 (2.94)**	−25.33 (3.26)**	−24.16 (3.22)**
Cubic performance	2.20 (0.22)**	1.22 (0.24)**	1.09 (0.24)**
WP SWL	−37.24 (5.34)**	−48.72 (5.59)**	−73.81 (5.53)**
WP EFF	23.56 (4.69)**	25.29 (4.89)**	40.07 (4.77)**
Level 2			
BP SWL	−56.53 (12.26)**	−53.34 (15.30)**	−64.56 (13.53)**
BP EFF	−3.33 (10.04)	2.00 (13.92)	20.19 (11.68)†
Level 1 *df*	1777	1777	1777
Level 2 *df*	195	195	195
ICC (between-person variance)	.43	.47	.55

Note. Intercept reflects performance at Minute 1. Parenthetical values indicate standard errors. SWL = subjective workload; EFF= effort; WP = within-person; BP = between-person.
† $p < .10$. * $p < .05$. ** $p < .01$ (two tailed).

Table 9

Summary of HLM Models Predicting Performance for Trials Involving an Increase in Task demand

Fixed effect	Trial 2	Trial 4
Intercept	924.72 (49.89)**	922.83 (41.49)**
Level 1		
Linear performance	121.24 (25.37)**	155.10 (21.23)**
Quadratic performance	–17.34 (5.07)**	–12.75 (4.65)**
Cubic performance	–0.81 (0.33)*	–1.05 (0.32)**
WP SWL	–43.62 (12.99)**	–80.33 (12.16)**
WP EFF	18.19 (5.17)**	52.58 (5.96)**
Linear Performance × WP SWL	7.29 (2.33)**	8.61 (2.10)**
Level 2		
BP SWL	–40.75 (18.93)*	–68.51 (23.53)**
BP EFF	–9.02 (15.14)	16.38 (21.07)
Level 1 *df*	894	876
Level 2 *df*	97	95
ICC (between-person variance)	.14	.18

Note. The intercept reflects performance at Minute 1. Parenthetical values indicate standard errors. SWL = subjective workload; EFF = effort; WP = within-person; BP = between-person.
† $p < .10$. * $p < .05$. ** $p < .01$ (two tailed).

Table 10

Summary of HLM Models Predicting Performance for Trials Involving a Decrease in Task Demand

Fixed effects	Trial 2		Trial 4	
Intercept	879.30	(30.86)**	890.82	(28.31)**
Level 1				
Linear Performance	170.88	(20.62)**	158.82	(18.44)**
Quadratic Performance	–44.95	(4.85)**	–36.51	(4.36)**
Cubic Performance	2.90	(0.34)**	2.17	(0.30)**
WP SWL	–96.40	(14.25)**	–102.87	(13.33)**
WP EFF	25.82	(13.17)*	39.85	(9.95)**
Linear Performance × WP SWL	23.76	(5.47)**	23.86	(4.86)**
Quad Performance × WP SWL	–1.98	(0.56)**	–1.98	(0.48)**
Linear Performance × WP EFF	–6.33	(2.41)**	–8.65	(1.92)**
Level 2				
BP SWL	–91.66	(26.07)**	–46.59	(15.54)**
BP EFF	22.55	(22.41)	–7.67	(11.69)
Level 1 *df*	874		892	
Level 2 *df*	95		97	
ICC (between-person variance)	.49		.52	

Note. The intercept reflects performance at Minute 1. Parenthetical values indicate standard errors. SWL = subjective workload; EFF = effort; BP = between-person; WP = within-person.
† $p < .10$. * $p < .05$. ** $p < .01$ (two tailed).

Table 11

Total, Direct, and Indirect Effects of SWL for Trials Involving Stable Task Demands

	Effect				
Trial	Total	Direct	Indirect	Z^a	95% CI limits[b]
1	−18.18 (4.04)**	−37.24 (5.34)**	19.06	5.01**	11.46, 26.43
3	−28.39 (4.48)**	−48.72 (5.59)**	20.33	5.16**	12.69, 28.04
5	−42.20 (4.32)**	−73.81 (5.53)**	31.61	8.33**	24.29, 39.12

Note. Relationships between subjective workload and performance through effort. No dynamic effects for trials that involved stable demands. Parenthetical values indicate standard errors. SWL = subjective workload.

[a] Sobel test of the indirect effect.

[b] Monte Carlo (MCMAM) confidence interval for the indirect effect.

† $p < .10$. * $p < .05$. ** $p < .01$ (two tailed).

Table 12

Total, Direct, and Indirect Effects of SWL for Trials Involving an Increase in Task Demand

	Effect				
Interval	Total	Direct	Indirect	*Z*[a]	95% CI limits[b]
		Trial 2			
1	−30.18 (12.46)*	−43.62 (12.99)**	13.44	3.51**	5.98, 20.97
7[c]	13.54 (7.05)†	0.10 (7.66)	13.44	3.51**	5.98, 20.97
9[d]	28.11 (10.08)**	14.67 (10.45)	13.44	3.51**	5.98, 20.97
		Trial 4			
1	−37.47 (11.58)**	−80.33 (12.16)**	42.86	8.72**	33.28, 52.47
7[c]	14.17 (6.21)*	−28.69 (7.64)**	42.86	8.72**	33.28, 52.47
9[d]	31.38 (8.79)**	−11.48 (9.96)	42.86	8.72**	33.28, 52.47

Note. Relationships between subjective workload and performance through effort. Parenthetical values indicate standard errors. SWL = subjective workload.
[a] Sobel test of the indirect effect.
[b] Monte Carlo (MCMAM) confidence interval for the indirect effect.
[c] Immediate performance following increases in task demand.
[d] Downstream performance following increases in task demand.
† $p < .10$. * $p < .05$. ** $p < .01$ (two tailed).

Table 13

Total, Direct, and Indirect Effects of SWL for Trials Involving a Decrease in Task Demand

	Effect				
Interval	Total	Direct	Indirect	Z[a]	95% CI limits[b]
		Trial 2			
1	−76.11 (11.63)**	−96.40 (14.25)**	20.29	1.96*	5.97, 21.00
7[c]	−34.76 (6.37)**	−25.22 (8.19)**	−9.54	−1.80†	−19.96, 0.83
9[d]	−52.71 (6.73)**	−33.22 (10.37)**	−19.49	−2.53*	−34.60, −4.35
		Trial 4			
1	−73.46 (10.22)**	−102.87 (13.33)**	29.41	3.99**	14.82, 44.11
7[c]	−39.75 (5.32)**	−30.88 (6.17)**	−8.87	−2.09*	−17.22, −0.32
9[d]	−60.16 (6.00)**	−38.53 (8.23)**	−21.63	−3.50**	−33.76, −9.37

Note. Relationships between subjective workload and performance through effort. Parenthetical values indicate standard errors.
[a] Sobel test of the indirect effect.
[b] Monte Carlo (MCMAM) confidence interval for the indirect effect.
[c] Immediate performance following decreases in task demand.
[d] Downstream performance following decreases in task demand.
† $p < .10$. * $p < .05$. ** $p < .01$ (two tailed).

Proposed model of the interrelationships between indicators of control subsystems

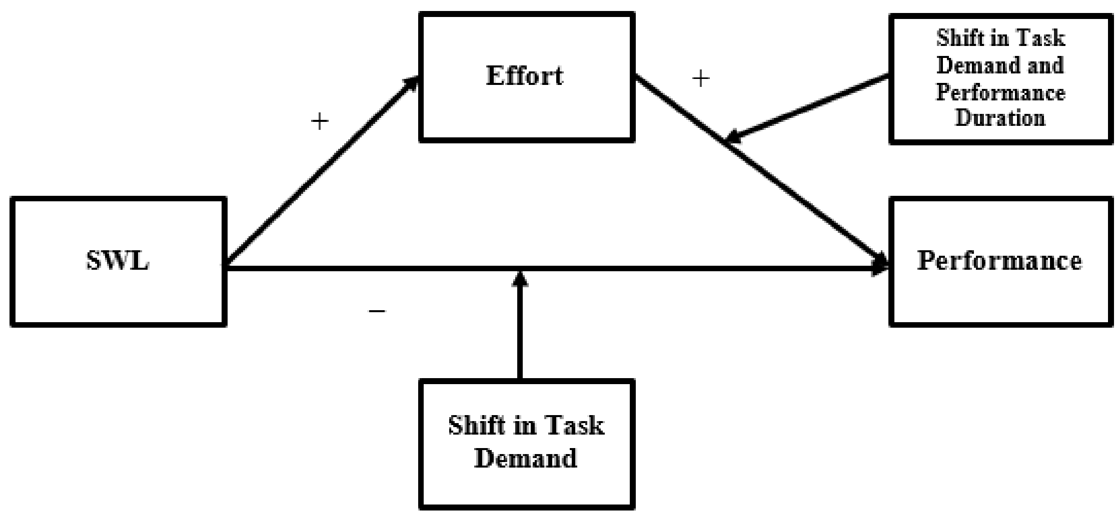

Figure 1. The direct and indirect effects of subjective workload on performance through effort. SWL = subjective workload.

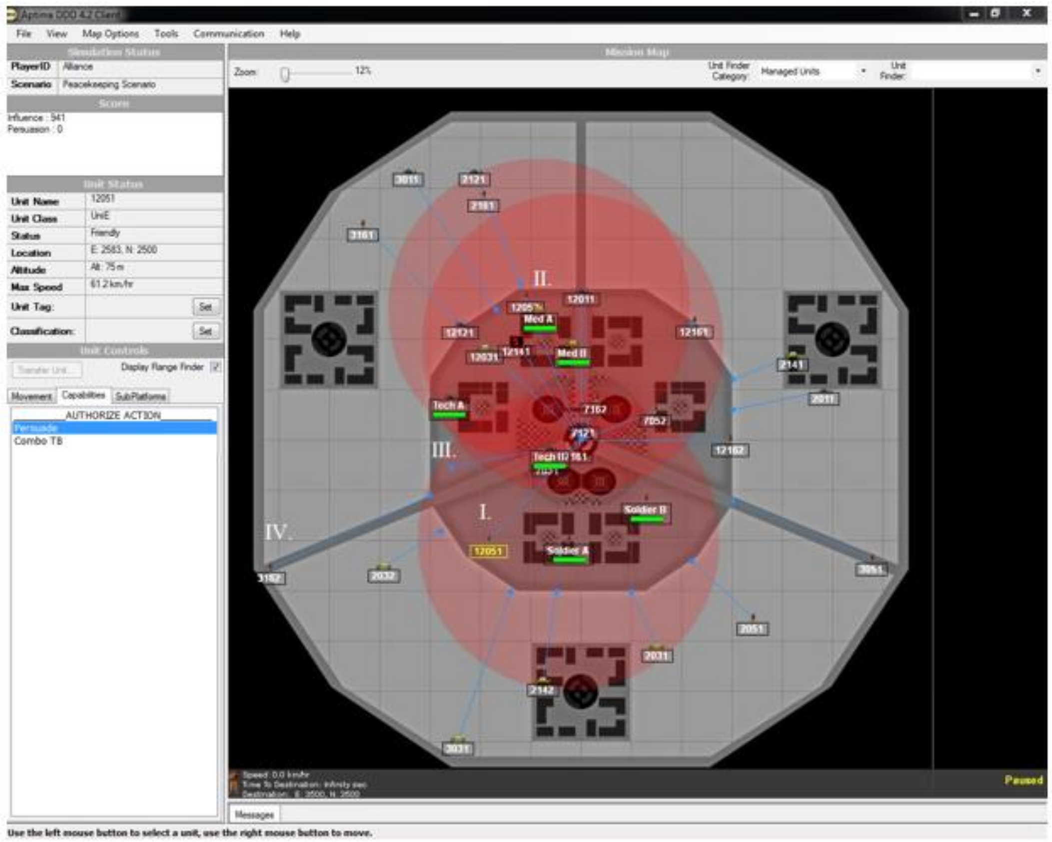

Figure 2. DDD map including control panel on left of the screen. Control panel displays influence and persuasion scores. Computer-controlled units move from the perimeter of the map towards the gathering place at the center of the restricted zone.

There are several key tasks being performed corresponding with the numeral on the map.

I: Unit 12051 is being detected and determined to be friendly.

II. Med A is persuading hostile Unit 12141.

III. Tech B is moving into position to persuade hostile Unit 3162 (IV).

Study Protocol

- Introduction and consent process (9 min)
- Demographics, video game experience, and questionnaires (20 min)
- Training presentation (15 min)
- Scripted training scenario (20 min)
- Pre-practice Trial (9 min)
- Practice Trial (11 min)
- Break (5 min)
- Trial 1: Routine trial consistent with Practice Trial (11 min)
- TLX Time 1 (5 min)
- Trial 2: Task demand shift trial (e.g., increase or decrease) beginning at min 6 and continuing until min 9 (counterbalanced with Trial 4) (11 min)
- TLX Time 2 (5 min)
- Trial 3: Routine trial consistent with Practice Trial (11 min)
- TLX Time 3 (5 min)
- Trial 4: Task demand shift trial (e.g., increase or decrease) beginning at min 6 and continuing until min 9 (counterbalanced with Trial 2) (11 min)
- TLX Time 4 (5 min)
- Trial 5: Routine trial consistent with Practice Trial (11 min)
- TLX Time 5 and task enjoyment (5 min)
- Debrief and dismiss (2 min)

Figure 3. Details involving 3-hour study protocol.

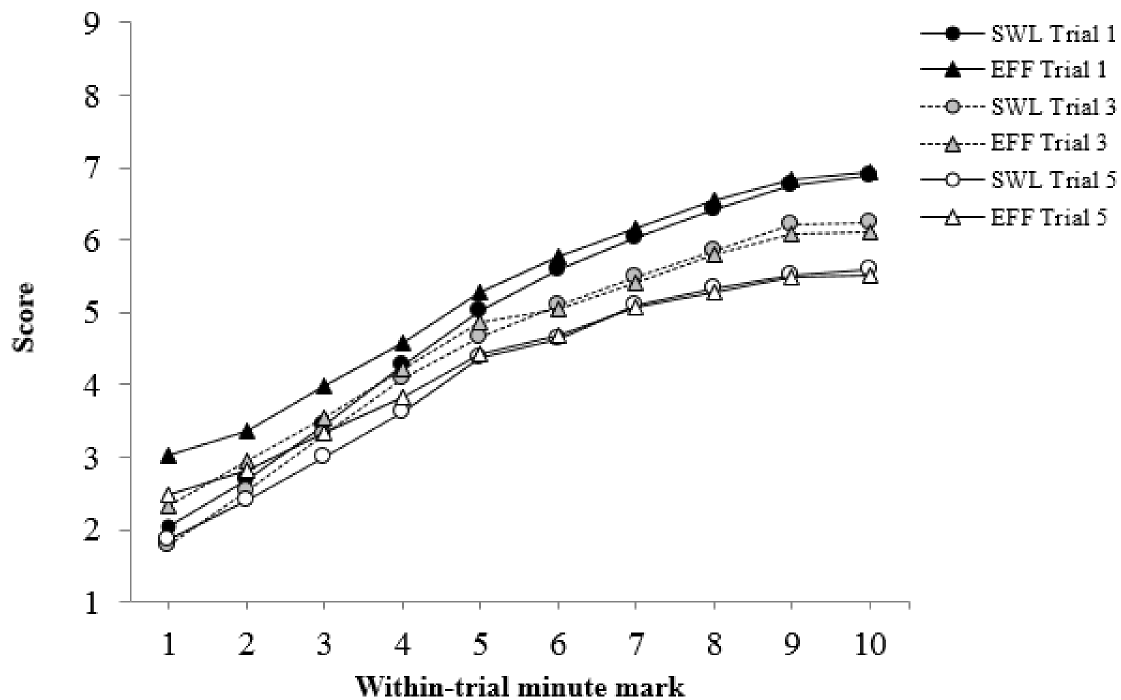

Figure 4. Single-item measures for trials represented by stable demands. SWL = subjective workload; EFF = effort.

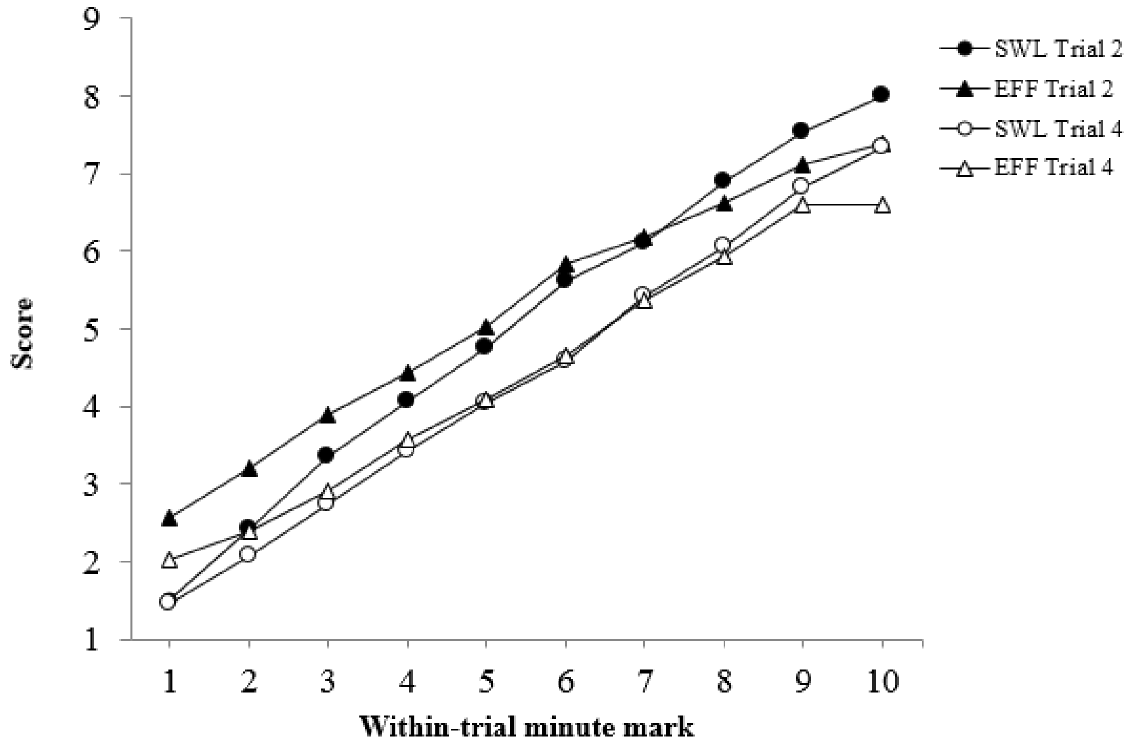

Figure 5. Single-item measures for trials that involved an increase in task demand. SWL = subjective workload; EFF = effort.

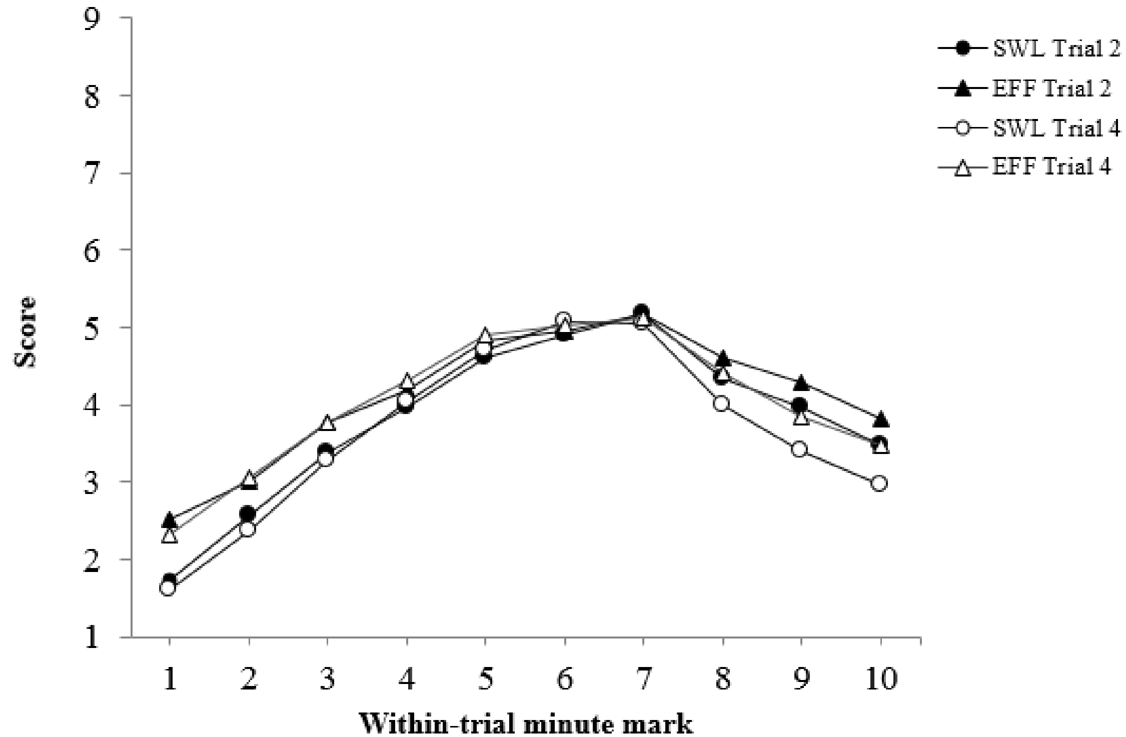

Figure 6. Single-item measures for trials that involved a decrease in task demand. SWL = subjective workload; EFF = effort.

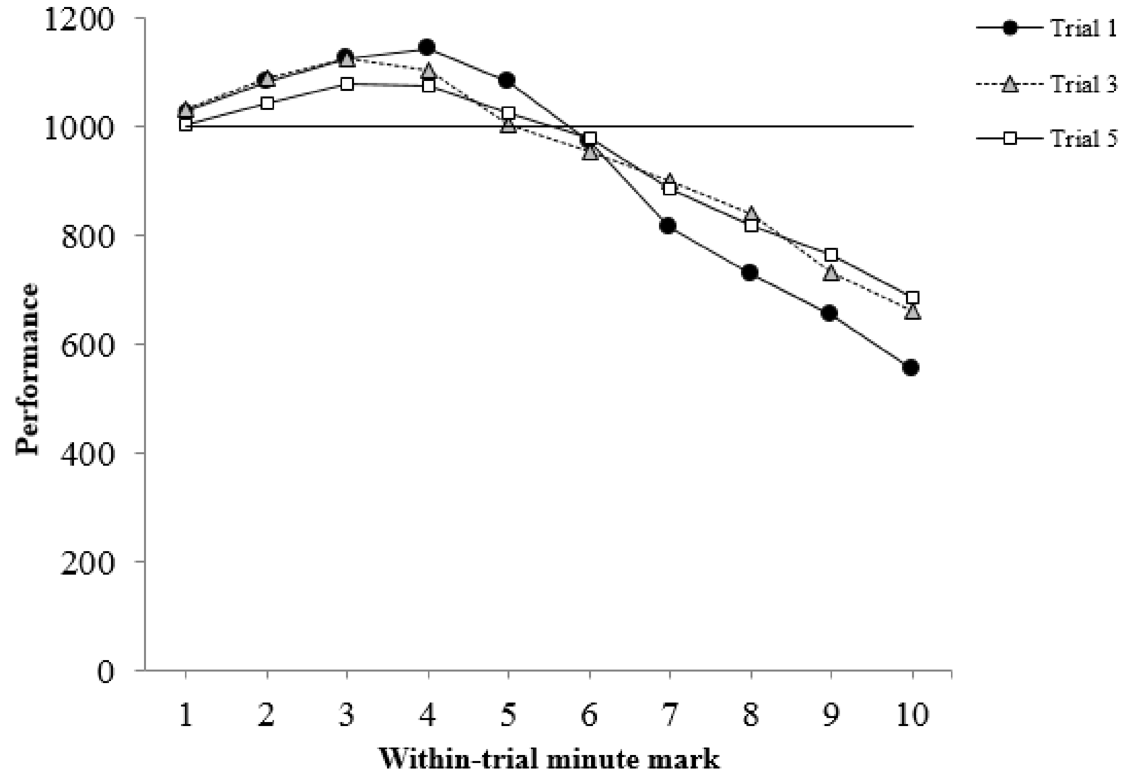

Figure 7. Performance for trials represented by stable task demands. SWL = subjective workload; EFF = effort. Performance scores begin at 1000.

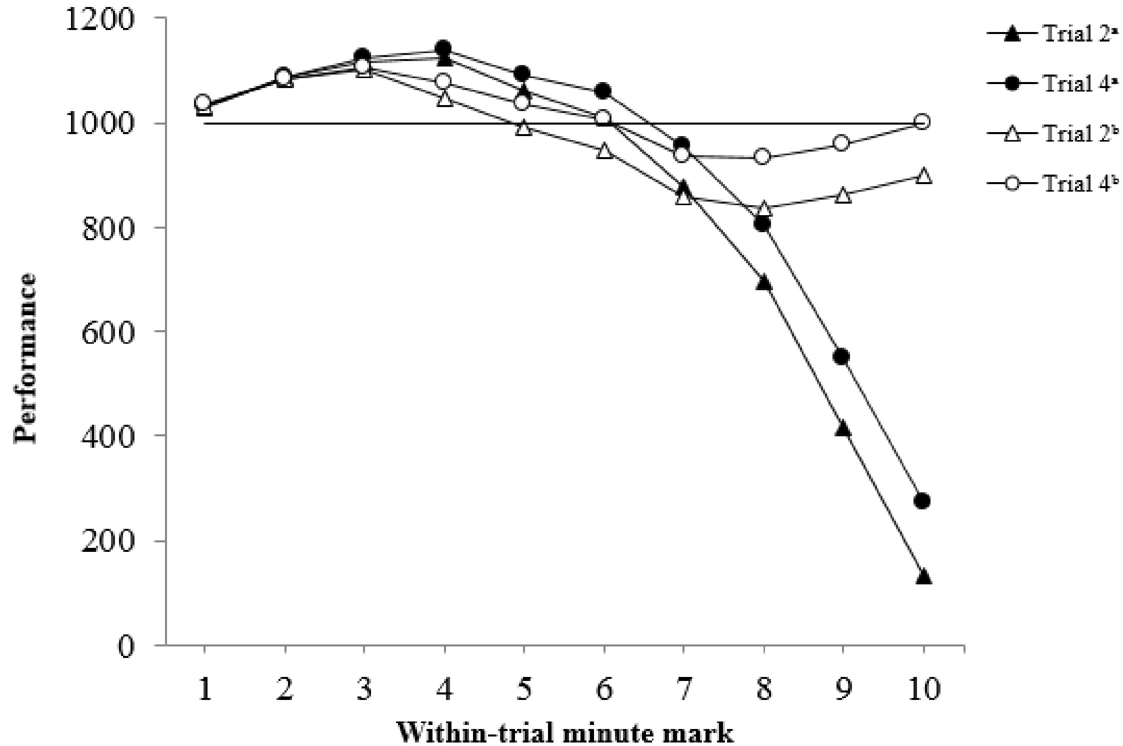

Figure 8. Performance for trials that involved an increase or decrease in task demands. SWL = subjective workload; EFF = effort. Performance scores begin at 1000.
[a] Trial that involved an increase in task demand
[b] Trial that involved a decrease in task demand

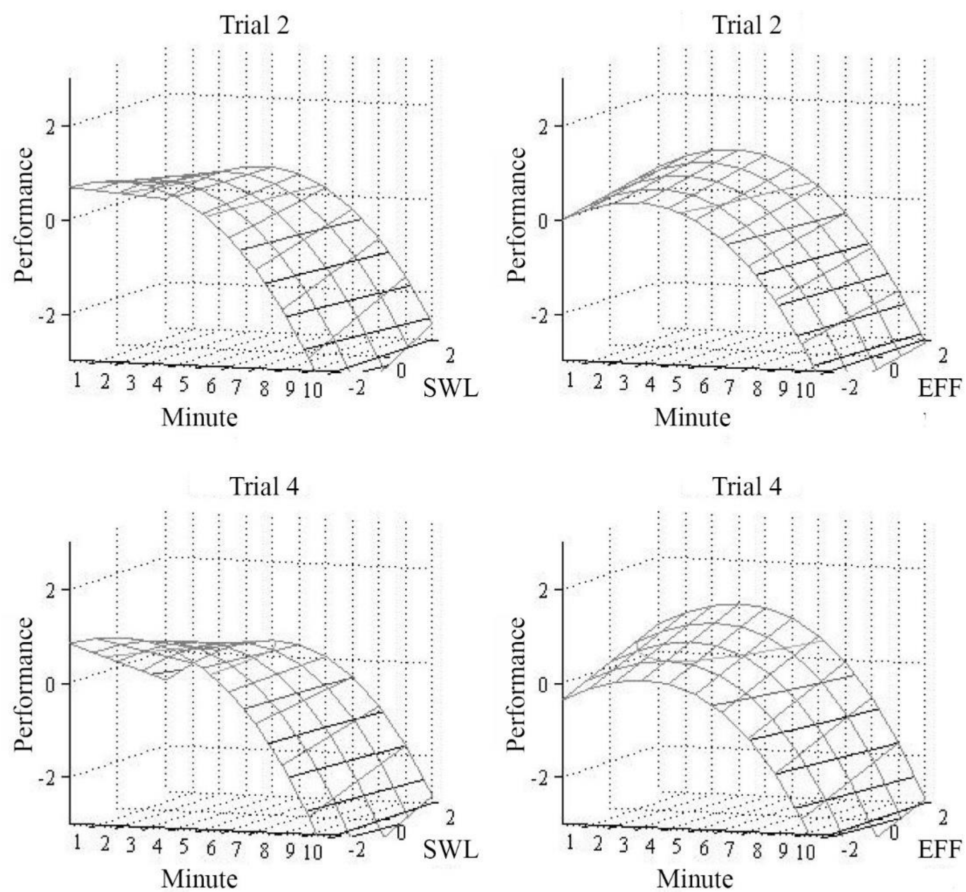

Figure 9. Interactions between the trajectory of performance and within-person effects of subjective workload and effort for trials involving an increase in task demand (starting at minute 5). SWL = subjective workload; EFF = effort. Subjective workload, effort, and performance reflect standardized scores.

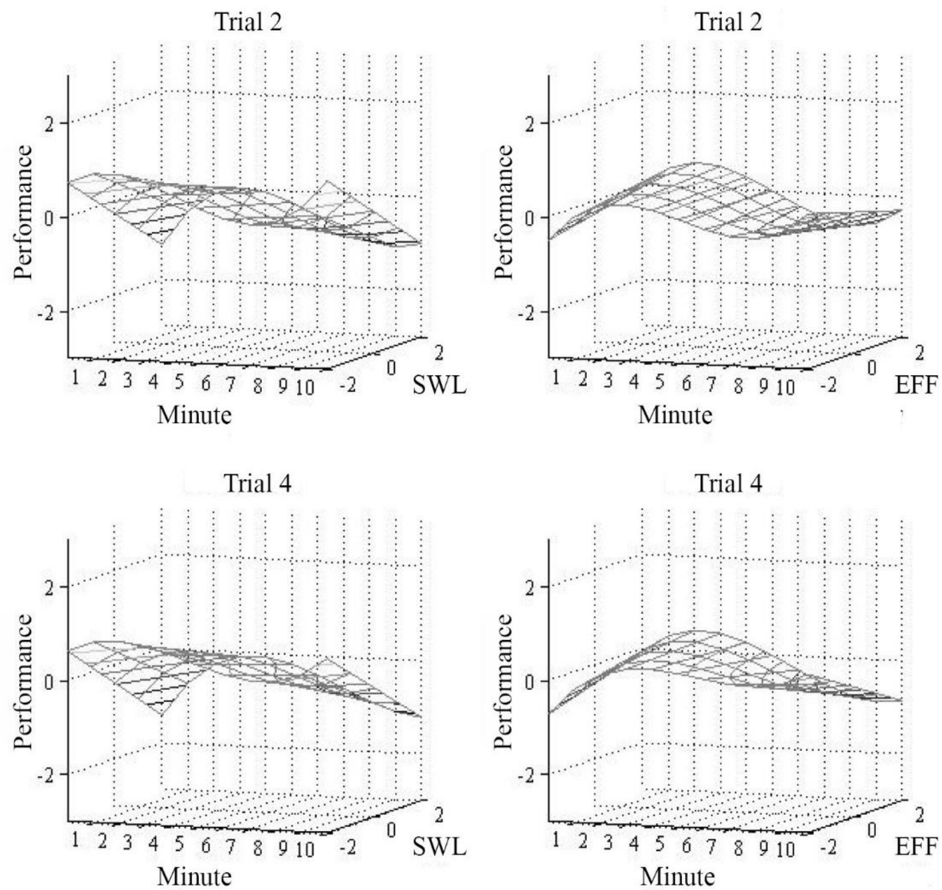

Figure 10. Interactions between the trajectory of performance and within-person effects of subjective workload and effort for trials involving a decrease in task demand (starting at minute 5). SWL = subjective workload; EFF = effort. Subjective workload, effort, and performance reflect standardized scores.