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Administration**

Reducing Major Rule Violations in Commuter Rail Operations: Distraction and Its Mitigation with Sustained Attention Training

Office of Research,
Development,
and Technology
Washington, DC 20590



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13. ABSTRACT (Maximum 200 words) Commuter rail accidents demonstrate the need to better understand how operator distraction affects rail safety. Veolia Transportation Services conducted two experiments in the Cab Technology Integration Laboratory (CTIL) using animated operating scenarios that were designed to simulate elements of distraction. In Study I, operational scenarios varied in task load, from baseline to low, and then to high load. The scenarios created operator distraction in locomotive engineers by means of task-load variation, which impacted both locomotive engineer performance and mental workload. Study II examined the ability of 3 hours of Sustained Attention Training (SAT) to mitigate distraction in a group of engineers. There were no statistically significant effects of SAT on any measure. However, there were trends indicating that SAT increased locomotive operator rule compliance compared to a control group that received no training. That these effects of SAT, though not statistically significant, were found consistently in the low task load condition, suggests that errors under this condition may reflect periodic lapses in attention associated with mind wandering or mental rumination. Future studies on mitigating distraction would be warranted with a larger sample of locomotive engineers and longer duration SAT.				
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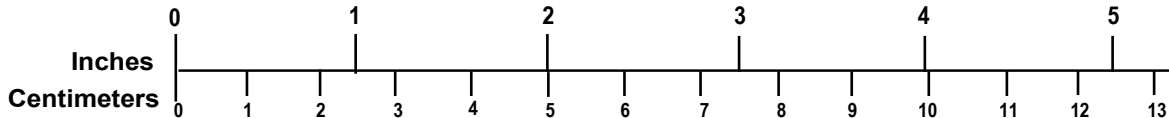
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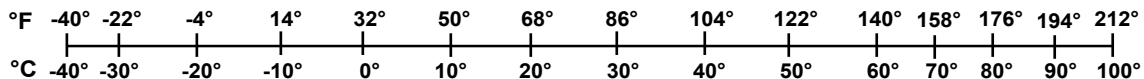
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Executive Summary

Commuter rail accidents demonstrate the need to better understand how operator distraction affects rail safety. To enhance the safety of commuter rail operations, sustained attention training may be able to reduce the effects of distraction on locomotive engineers' performance.

Veolia Transportation Services (Veolia) conducted two controlled experiments, sponsored by the Federal Railroad Administration (FRA), in the Cab Technology Integration Laboratory (CTIL) simulator, which used simulated operating scenarios that were designed to simulate elements of distraction. In the first study (Study I), operational scenarios developed to vary in task load were effective in creating operator distraction in certified¹ locomotive engineers. In the second study (Study II), 3 hours of Sustained Attention Training (SAT) were administered to a group of certified locomotive engineers. When the Study II participants operated the CTIL, a limited improvement was seen in the locomotive operators' compliance with rules versus a control group that received no training. The studies were conducted as follows:

Study I

Twelve locomotive engineers were evaluated for operational rule compliance and distraction-related errors during each of the three simulated railroad operational scenarios: Baseline, Low Task Load, and High Task Load. Both subjective and objective measures indicated that the mental workload was lowest in the baseline condition, higher in the Low Task Load condition, and highest in the High Task Load condition.

The level of compliance with temporary speed restrictions was lower than the level of compliance with permanent speed restrictions, with both being less than the industry standard expectation. General rule compliance (e.g., horn usage, radio procedure) and appropriate reaction to unusual events were also less than expected.

In general, there were no statistically significant effects of task load on compliance rates, probably reflecting the relatively small sample size of participants, but compliance was typically lower under the High Task Load scenario than under the Low Task Load scenario. The operating scenarios were effective in simulating real-life situations as well as in creating operator distraction by means of task-load variation; thus, providing a suitable foundation for evaluating distraction effects on operator performance in Study II.

Study II

Twenty-four test participants were randomly assigned to one of two groups. One group received SAT plus general information on crew resource management (CRM) training, while the control group was exposed to CRM information only. Both groups participated in the Low Task Load and High Task Load scenarios developed in Study I.

The results confirmed that Study I contained operational scenarios that have varied operational task loads successful in inducing graded levels of difficulty for different aspects of locomotive engineer performance. Both objective and subjective approaches to measuring mental workloads indicated that the two locomotive engineering scenarios were graded by task load and

¹.Certified / Certification according to Title 49, Code of Federal Regulations (CFR) Part 240

operational difficulty. Although there were no statistically significant effects of SAT on attentional errors, mental workload, or performance, there were several trends pointing to the effectiveness of SAT in the Low Task Load condition. In this condition, but not the High Task Load condition, there were trends that indicated the effectiveness of SAT for three measures: subjective mental workload, objective mental workload (working memory ordered recall), and compliance with procedures for dealing with unusual events.

That the effects of SAT (though not statistically significant) were found consistently in the low task load condition suggests that errors under low task load may reflect periodic lapses in attention associated with mind wandering or mental rumination. A significant limitation of this study is that the sample size (N=24) was relatively small for detecting small to medium size effects of SAT. In addition, the duration of training used in the current study (about 3 hours) was very short in comparison to previous studies of attentional training, which have found that performance is improved only after several hours or days of training.

1. Introduction

Recent commuter rail accidents and analyses of rule violations highlight the need for better understanding of the contributory role of operator distraction in such violations [1]. Distracted driving has been thoroughly studied in recent years [2], but distraction during rail operations has not been as thoroughly examined. There are many types of rule violations that can be committed by a locomotive engineer; for example, one major violation in passenger rail operations is failing to stop at a red signal. Other significant violations occur when train operators² fail to comply with a speed restriction or move operating equipment into a track segment without authority. The potential consequence of such violations can be staggering: for example, a red signal violation can lead to a collision that could result in injuries, loss of life, a major chemical spill, or substantial equipment damage.

1.1 Background

A number of engineering controls have been implemented to prevent these types of errors and ensure that operating rules, which are dependent upon voluntary (albeit required) human compliance, are followed. For instance, railway-side control signals are part of a complex integrated system designed to be electro-mechanically failsafe, while locomotive engineers and conductors are required to verbally acknowledge signal indications, speed restrictions, and other key operating directives with one another via live or radio communication. This, as a result, provides a verbal/audio cue to the operator to initiate the appropriate operational control response (e.g., slow down, stop).

Surprisingly, despite strict operating rules and ongoing training, red signal and other serious rule violations continue to occur. Figure 1 shows a decade of data on stop signal violations per million track miles (MTM) of US rail operations. As these data indicate, rule violations continue to be a stubborn source of error in rail operations, do not show any trend to diminish, and demand effective counter measures.

Even when rule violations do not result in an accident, disciplinary action is usually taken against the crew, which results in the suspension or termination of employment; the implication being that the failure to comply with a rule is the end result of willful operator negligence. However, this conclusion does not explain why a rail operator (the majority of whom are well trained, experienced and not otherwise impaired) would commit such a gross act of negligence that could result at least in the loss of employment, or at worst, personal injury or even death.

²As used in the context of this report, the terms “Operator,” “Engineer,” and “Locomotive Engineer” are synonymous and interchangeable titles.

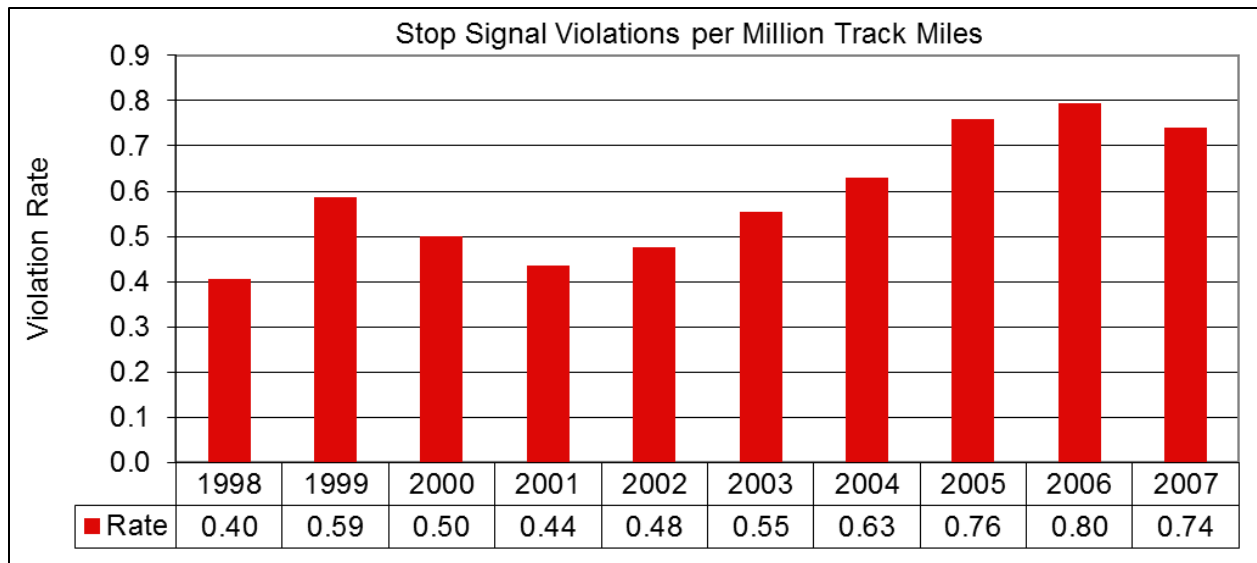


Figure 1. Stop Signal Violations per Million Track Miles (MTM) in U.S. Rail Operations, 1998-2007

(Source: FRA data per 49 CFR Part 240.309)

Human factors system analyses of rail operations suggest an alternative explanation: that a combination of equipment, operator, and environmental factors affect safety compliance [3]. From this perspective, a common set of circumstances are associated with an operator’s *loss of attentional resources*, *confirmation bias*, or *inattentive blindness*, which are characteristic of normal human behavior:

- **Attentional resources:** People have a finite capacity for attention; consequently, if the resources available for a primary task are depleted, e.g., by multitasking or fatigue, performance of the primary task will suffer [4].
- **Confirmation bias:** The natural human tendency to focus on specific signs that confirm an initial idea or decision, rather than all relevant sources of information [5].
- **Inattentive blindness:** The finding that humans are not consciously aware of *all* the objects that are present in a visual scene, and can miss even salient objects if their attention is diverted elsewhere [6]. Each of these phenomena can compromise human operator performance, with the ultimate result being an error or rule violation, that could, depending on other factors, result in an accident or near miss.

Human factors are the leading cause of incidents and accidents in U.S. rail operations (Figure 2 and Figure 3). Over the period 2004-2013, 38% of all such cases involved human factors. This figure is similar to that reported in other transportation domains, such as commercial aviation. Failures of attention are a leading contributor within the human factors category [7].

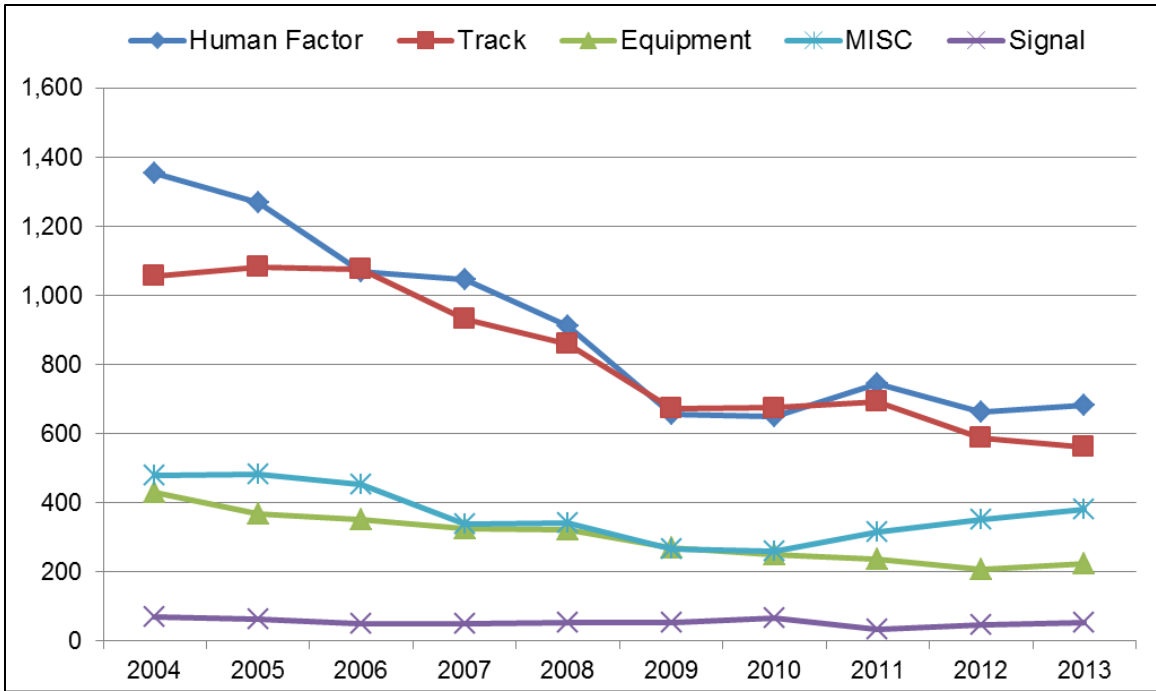


Figure 2. Ten-Year Trend in Train Accidents in U.S. Rail Operations by Causal Factor, 2004-2013
(Source: FRA Accident Database)

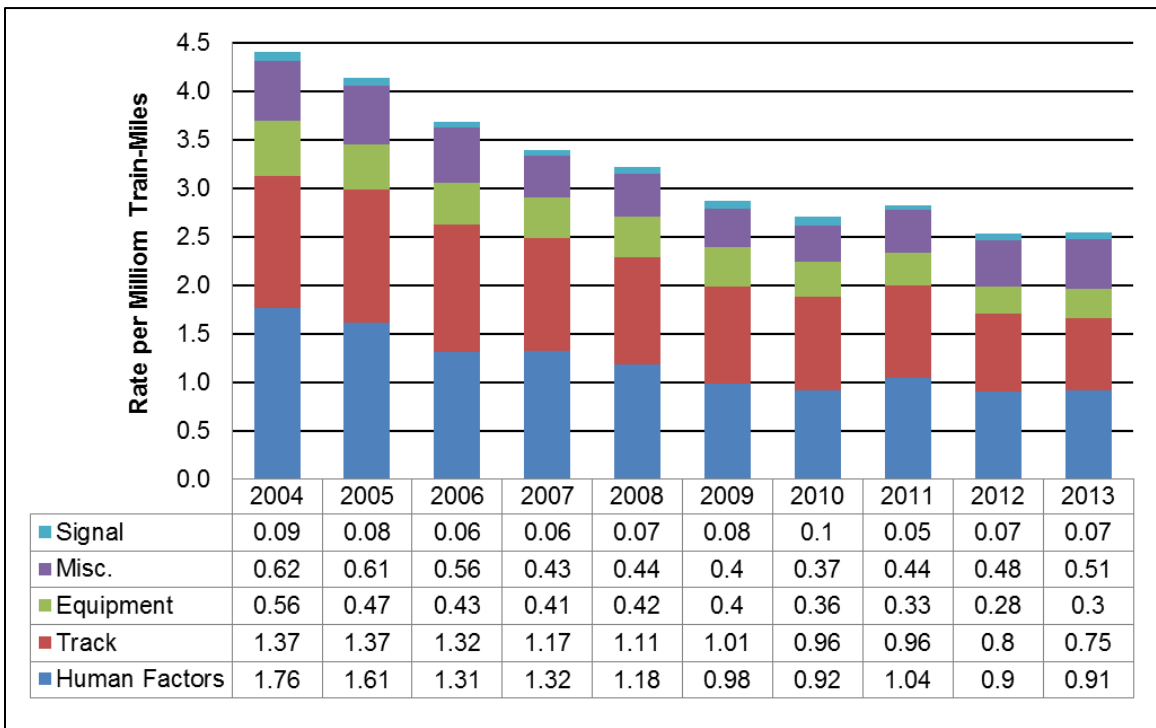


Figure 3. Causal Factors in Train Accidents per Million Track Miles (MTM) in U.S. Rail Operations, 2004-2013
(Source: FRA Accident Database)

While there has been a slight downward trend in recent years in the overall rates of accidents reported to FRA, the proportion of human factors-related accidents continues to be relatively high (Figure 4).

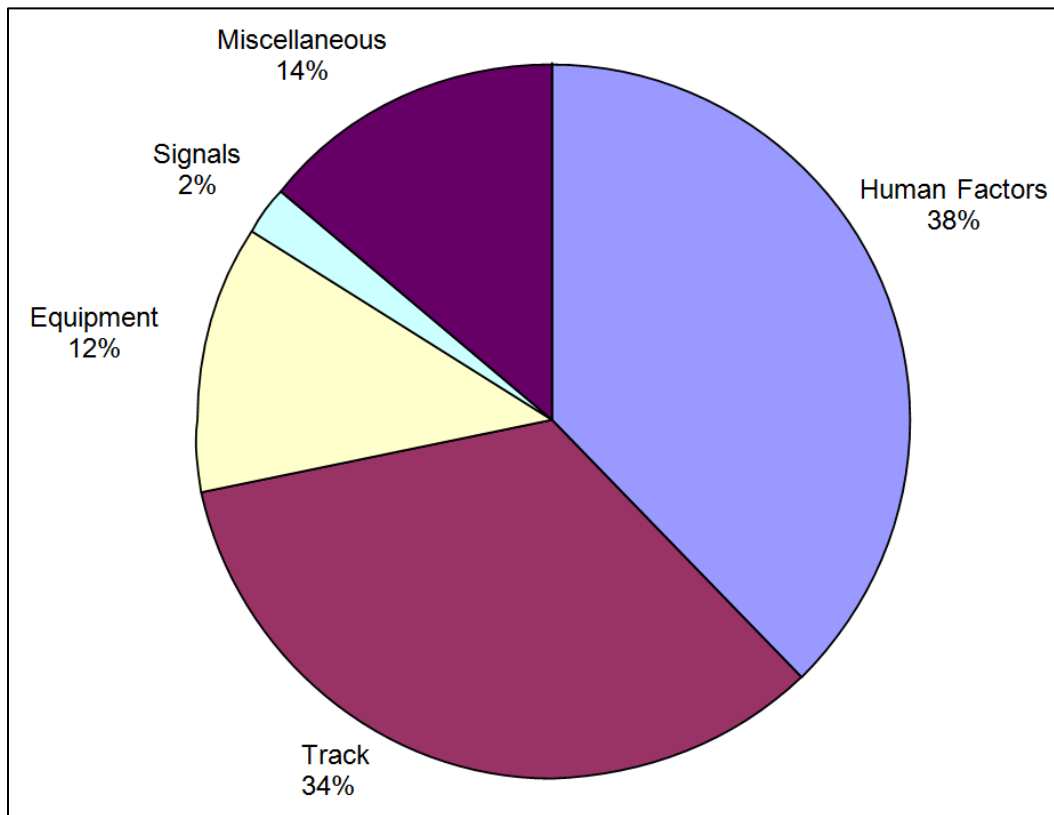


Figure 4. Total Reportable Train Accidents per MTM by Cause, 2004-2013

1.2 Objectives

While accident analysis and field studies of locomotive engineers have yielded some insights into distraction, there is a need for empirical studies of locomotive engineer performances using simulations. In automobile driving research, numerous simulators are available for empirical studies, ranging from low-cost desktop driving software to medium-fidelity motion-enabled driving simulators and high-fidelity full-motion simulators [8]. However, railroads do not have simulators dedicated for research. In March 2010, FRA sponsored the development and installation of a high-fidelity locomotive simulator, the Cab Technology Integration Laboratory (CTIL). The CTIL was installed at the Volpe National Transportation System Center in Cambridge, MA. The CTIL design allows users to evaluate new locomotive technologies before they are installed in actual locomotive cabs; prototype new locomotive-engineer equipment/control interface and display concepts; and assess engineer distraction, mental workload, and performance in simulations of diverse operational conditions.

1.3 Overall Approach

This project was conducted as a two-part study at the CTIL facility on the role of distractions in commuter rail operations and the possibility of mitigating distraction with training. We recruited experienced locomotive engineers from the Massachusetts Bay Commuter Railroad (MBCR) and

they operated the CTIL simulator over animated track segments while experiencing scenarios differing in operational task load and potential for inducing distraction. In the first of two studies, we systematically varied operational task load over three levels (Baseline, Low Task Load, High Task Load) and assessed the effects of each task load on locomotive engineer performances and their distraction-related errors. The goal of the first study was to develop and evaluate task scenarios that represented the operational environment and would successfully trigger elements of distraction that would be manifest in locomotive engineer performance. In the second study, we examined the possibility of mitigating distraction by training a separate group of locomotive engineers in Sustained Attention Training (SAT), then giving them the Low Task Load and High Task Load scenarios developed in Study I.

1.4 Scope

The overall approach was an effective method for meeting the study objectives. It provided empirical validation of distraction-related errors in the CTIL simulation, and then proved useful when the team examined potential mitigation with SAT. However, due to finite resources and time delays, the scope was limited. First, only relatively small samples of locomotive engineers could be tested (a total of 12 in Study I and 24 in Study II). Since the study was limited to locomotive engineers who performed in a high-fidelity commuter rail operations environment, the study results may not necessarily generalize to all locomotive engineers or to all rail and transit operations. Secondly, technical delays due to CTIL hardware/software changes and budget constraints also limited to three hours the duration of time available to administer SAT to the Study II training group.

2. Study I

In Study I, three simulated scenarios were designed and programmed into the CTIL locomotive simulator. Locomotive engineer participants interacted with the scenarios and their reactions to the scenarios were measured. The scenarios varied in the number of events and unusual occurrences displayed, with the intention of creating a varying degree of distraction for the operator, primarily by means of task overload/underload..

Three scenarios were developed for use in Study I: (1) a scenario that simulated the task load associated with normal operations (Baseline); (2) a moderately difficult scenario that added task demands and unexpected events to the Baseline scenario (Low Task Load); and (3) a challenging scenario that added to the moderately difficult scenario with additional off-normal events (High Task Load). The scenarios were developed such that the physical characteristics of the simulated railroad—i.e., the beginning and ending points, passenger station locations, gradient, curvature, bridges, etc.—were common to all scenarios. However, scenarios 2 and 3 included additional task elements that made their operation progressively more challenging. Thus, scenarios 1, 2, and 3 were designed to be progressively more challenging, but with common task elements as well, so that we could identify the effects on performance, if any, of the additional task elements. We anticipated that any potential effects of distraction would be observed in performance deviations, compared to Baseline scenario, in the moderately difficult and challenging scenarios.

2.1 Methods and Experimental Design

2.1.1 Participants

A total of 12 MCBR locomotive engineer volunteers participated in the study. Their ages ranged from 28 through 62 years old (10 male, 2 female; mean 44 years, standard deviation 9.98) and had between 4 and 30 years of operational experience (mean 16.33 years, standard deviation 9.9). All participants were locomotive engineers with current licenses and each participant performed all three operational scenarios with the order of the scenarios counterbalanced between participants. At the end of each scenario, participants were asked to provide a subjective rating of the mental workload they experienced during the scenario on a scale from 1 to 10, where 1 represented minimal or no workload, and 10 represented extremely high workload.

Study I required a full 8- to 10-hour day for each of the 12 participants (as follows):

- 08:00 – 08:30: Participant arrives at Volpe, is processed through security, issued credentials, and escorted to the CTIL lab.
- 08:30 – 09:00: Participant is introduced to Volpe personnel, chief investigator, the subject matter expert in CTIL-operation for locomotive engineers, and is provided with a tour of lab facilities, orientation with facility amenities, and safety briefing.
- 09:00 – 10:00: Experimental liability release/consent form, survey, and administrative documents are collected; the orientation scripting is read, a thorough technical job briefing is conducted (which includes an operating territory engineering line chart, timetable, permanent speed restrictions, rules in effect and special instructions).

- 10:30 – 11:00: Participant operates the CTIL Baseline scenario for 30 minutes with assistance from the subject matter expert in order to gain an understanding of the operational characteristics of the equipment in relationship to the simulated operational scenarios.
- 11:00 – 12:30: Participant receives the operating paperwork that is required to operate Study I's Baseline scenario. He or she is isolated within the CTIL confines. Participant responds to operating directions from the Train Dispatcher via simulated radio communication until the conclusion of the scenario.
- 12:30 – 13:00: Catered lunch break.
- 13:00 – 14:30: Participant receives operating paperwork necessary to operate Study I's scenario 2. He or she is isolated within the CTIL confines until the conclusion of the scenario.
- 14:30 – 16:00: Participant receives operating paperwork necessary to operate Study I's scenario 3. Participant is isolated within the CTIL confines, proceeding until the conclusion of the scenario.
- 16:00 – 16:30: Participant is debriefed, interviewed, and released.

2.1.2 CTIL

The CTIL is a tool to: (1) demonstrate and assess the human machine-interface (HMI) of new technologies, prototype workstations configurations, and examine operating procedures by evaluating human performance; and (2) help reduce the risk of human errors by identifying potential HMI system and operational weaknesses and developing improvements in system design, training, and/or procedures to address those risks. The full CTIL facility includes a physical locomotive cab with standard displays and controls, out-of-the-window displays of naturalistic scenes provided by a dedicated computer with a powerful graphics engine and software for scenario development, execution, and full data capture, including both locomotive and engineer performance parameters.³ The CTIL is shown in more detail in Figure 5, Figure 6, and Figure 7.

Scenarios

The scenarios involved the simulated operation of a typical MBCR commuter train consisting of one-SD-40 locomotive pulling five coaches over the MBCR Providence line from Mile Post (MP) 181 (Cranston Yard) to MP 229.7 (South Station), a total distance of 48.7 miles. The method of operation was by a centralized Train Control System (TCS), under the direction of a train dispatcher, supplemented in the field by Automatic Block wayside signals. The scenarios were displayed on full-panel flat-screen monitors in both forward-facing windshields of the CTIL and side-window views for both sides of the cab. A 1-hour continuous audio loop of recorded railroad radio transmission traffic between various train dispatchers, operating crews, and railroad wayside personnel played continuously in the background of the CTIL, simulating a realistic field operational environment.

³CTIL hardware, software, and operating system for Study I were provided by Alion Science and Technology, Inc.; CTIL hardware, software, and operating system for Study II were provided by Corys Thunder, Inc.



Figure 5. Cab Technology Integration Lab (CTIL)



Figure 6. Inside View of CTIL Cab



Figure 7. Example of Out-of-Window View from CTIL Cab

The experimenter was located remotely in a separate control room and had direct visual/audio observation of each test subject operating the CTIL via in-board cameras and microphones. The experimenter also performed the roles of the virtual train dispatcher, on-board crew-member, and wayside employee(s), providing normal and essential operating information and mandatory directives via simulated 2-way radio communication with the test-subject operator.⁴ The experimenter closely followed designated scripts created for each scenario, detailing communications initiated by the operator/locomotive engineer, virtual train dispatcher, field personnel, or on-board crewmember; as well as the responses required by operating rules and radio procedures. All video, audio, and CTIL control functions were recorded.

Participants were required to comply with the current railroad operating rules that they were familiar with concerning operating authority, track bulletins in effect, restrictions, and radio and emergency procedures.⁵ Additionally, operators were briefed prior to the start of the study on operational paperwork, rules in effect, procedures for memory tests (described later), and the need to perform their job functions in the CTIL in the same manner as they normally would on the job.

In all scenarios, engineers were also periodically asked to perform a short working memory task requiring them to report back, after a short delay, numbers that were read out to them by the experimenter. The rationale for using this task was to simulate the effects of other internal or external sources of distraction that engineers may be prone to experience, as well as to have another performance measure that may be sensitive to task difficulty.

⁴The experimenter had extensive experience as a railroad train dispatcher and engineering employee.

⁵Northeast Operating Rules Advisory Committee (NORAC) Operating Rules 10th edition, effective November 6, 2011; MBCR Special Instructions & Safety Rules; fictitious timetable, Special Bulletin, and temporary speed restrictions (TSRB) based on NORAC/MBCR standards.

As mentioned previously, each of the three scenarios was designed to have common task elements, but also additional task elements that made Scenario 2 more challenging than Scenario 1, and Scenario 3 in turn more challenging than Scenario 2.

Baseline Task (Scenario 1)

The baseline or control scenario was designed to simulate routine operations representing the normal level of difficulty of the Cranston Yard to South Station route of the virtual MCBR Providence line. Engineers completed the 48.7 mile run with no Temporary Speed Restriction Bulletins (TSRB) in effect. There were also no unforeseen speed restrictions or unusual occurrences. The following task elements were present (summarized in Table 1).

1. Four permanent speed restrictions listed on the “Providence to Boston” timetable page, located at the following Mile Post (MP) markers:
 - MP 185.9 -191.7: 60 miles per hour (mph)
 - MP 195.5-198.6: 50 mph
 - MP 203.0 – 204.0 45 mph
 - MP 213.6-214.1: 50 mph.
2. Numeric Working Memory Task. Engineers were asked to store 8 numbers verbally transmitted via radio by the experimenter in memory and reproduce them in order after a 5-second delay. This task was repeated 4 times, 3 times during the simulation while in motion, and one time while the train was stopped. The working memory task⁶ was presented at:
 - MP 186
 - MP 207
 - MP 214
 - MP 227.6 (Back Bay PS) Stationary.
3. General Rule Compliance. Locomotive engineers’ general rule compliance was evaluated with regard to standard radio communication procedures, and the use of the locomotive horn at highway grade crossings (HGX) at:
 - Main Street HGX MP 181.9 (horn)
 - Hogan Hwy HGX MP 191.7 (horn)
 - Urban Ave HGX MP 192.2 (horn)
 - Approach Signal CP Isaacs MP 204.1 (Radio Procedure)
 - HAWK Radio Announced HBD MP 206.7 (Radio Procedure)
 - Mohawk Rd HGX MP 209.5 (horn)
 - JB Waterman HGX MP 216.4 (horn)
 - Approach Signal CP 227 MP 227 (Radio Procedure)
 - Approach Signal So. Station MP 228 (Radio Procedure).

⁶Memory task MPs were chosen strategically before speed restrictions or other conditions contributing to distraction.

Table 1. Summary of Task Elements Present in Scenarios 1, 2, and 3

Task Elements	Baseline (Scenario 1)	Low Task Load (Scenario 2)	High Task Load (Scenario 3)
Permanent Speed Restrictions	MP 185.9 -191.7: 60 mph MP 195.5-198.6: 50 mph MP 213.6-214.1: 50 mph Mansfield Siding: 45 mph	MP 185.9 -191.7: 60 mph MP 195.5-198.6: 50 mph MP 213.6-214.1: 50 mph Mansfield Siding: 45 mph	MP 185.9 -191.7: 60 mph MP 195.5-198.6: 50 mph MP 213.6-214.1: 50 mph Mansfield Siding: 45 mph
Working Memory Task	8 numbers: Presented at MP 186, 207, 214, 227.66 (Backbay PS, Stationary)	8 numbers: Presented at MP 186, 207, 214, 227.66 (Backbay PS, Stationary)	12 numbers: Presented at MP 186, 207, 214, 227.66 (Backbay PS, Stationary)
Temporary Speed Restrictions	None	MP 183.4 -183.5: 10 mph MP 199.5-200: 25 mph	MP 183.4 -183.5: 10 mph MP 194.5 - 194.6: 10 mph MP 199.5-200: 25 mph MP 214.9-215.4: 20 mph
General Rule Requirements	Horn Use at HGX (5) Radio Procedures (4)	Horn Use at HGX (5) Radio Procedures (10)	Horn Use at HGX (5) Radio Procedures (15)
Unusual Events	None	MP 204.8: Signal Malfunction Mansfield Interlocking MP 216.4: Vehicle in foul JB Waterman Rd MP 223: Trespasser on ROW	MP 207: Vehicle in foul MP 217: Signal Malfunction CP Elsmore MP 221: Trespasser on ROW

Low Task Load (Scenario 2)

The Low Task Load condition of Scenario 2 consisted of the same 48.7-mile run as the Baseline condition of Scenario 1, but with the following *additional* task elements:

1. Temporary Speed Restrictions/Bulletins were in effect between the following locations:

MP 183.4 to MP 183.5: 10 mph

MP 199.5 to MP 200: 25 mph

MP 218.5: MBCR Bull # 3-12 Protect Men & Equipment Foreman Gonzales

2. Unusual Events:

MP 204.8: Signal Malfunction Mansfield Interlocking (Dropped to Red)⁷

MP 216.4: Vehicle in close proximity to tracks JB Waterman Rd

MP 223: Trespasser on right-of-way

General Rule Requirement:

Receive Form D Rule 138⁸ S&P Mohawk Road MP 204 (Radio Procedure)

Signal Malfunction MP 205.6 (Radio Procedure)

Form D Rule 138 S&P Mohawk Road MP 209.5 (Radio Procedure)

Vehicle in ROW, JB Waterman HGX MP 216.4 (Radio Procedure)

Form D Maintenance of Way (MOW) Protect Employee in Charge (EIC) Gonzales MP 218.5 (Radio Procedure)⁹

Trespasser on ROW MP 223 (Radio Procedure).

High Task Load (Scenario 3)

The High Task Load condition of Scenario 3 consisted of the same 48.7 mile run as the Low Task Load condition of Scenario 2, but with the following *additional* task elements:

1. Temporary speed restrictions in effect:

10 mph MP 183.4 to MP 183.5

10 mph MP 194.5 to MP 194.6

25 mph MP 199.5 to MP 200.0

20 mph MP 214.9 to MP 215.4

MBCR Bull # 3-12 Protect Men & Equipment MP 218.5, Foreman Gonzales (

2. Unusual events:

Vehicle in foul MP 207

Signal Malfunction CP Elsmore MP 217

Trespasser on ROW MP 221

⁷A wayside control signal visible to the control operator on approach to display a “Proceed” indication (Green or Yellow aspect) that unexpectedly changes to a more restrictive indication “Stop” indication (Red aspect).

⁸Rule 138-A Mandatory Directive issued by train dispatcher to the train crew advising them of the reported failure of the automatic grade-crossing protective devices at a particular crossing, requiring that train movement stop prior to proceeding through the crossing under flag protection.

⁹Form D Maintenance of Way-A Mandatory directive issued by the train dispatcher verbally or in writing to operating crews as notification of track locations obstructed for maintenance per NORAC Rule 135. The *Employee in Charge* (EIC) is the designated watchman for the workgroup who coordinates with approaching trains for movement authority.

3. General rule requirements:

Receive Bridge Strike Order¹⁰-Kiley Lane at Providence PS MP 185.1 (Radio Procedure.)

Receive Form D M-4 (MOW Protect EIC Jones at Attleboro PS MP 196.9 (Radio Procedure.)

Form D M-4 (MOW Protect EIC Jones at Attleboro PS MP 202.2 (Radio Procedure.)

Receive Form D M5 (Rule 138 S&P Mohawk Rd. at Mansfield PS MP 204.0 (Radio Procedure.)

Vehicle on ROW MP 207 (Radio Procedure.)

Form D M5 Rule 138 S&P Mohawk Rd MP 209.5 (Radio Procedure.)

Receive Form D M-8 (MOW Protect EIC Gonzales at Sharon PS MP 210.8 (Radio Procedure.)

Form D M-8 (MOW Protect EIC Gonzales MP 216.3 (Radio Procedure.)

Signal Malfunction CP Elsmore MP 217 (Radio Procedure.)

Form D (MOW Protect EIC Gonzales MP 218.5 (Radio Procedure.)

Trespasser in ROW MP 221 (Radio Procedure.)

4. Higher working memory load:

Whereas 8 numbers were presented from delayed recall in the Baseline and Low Task Load conditions (Scenarios 1 and 2), 12 numbers were presented in the High Task Load condition (Scenario 3).

2.2 Results and Analysis

We first evaluated whether the three operational scenarios we developed were associated with progressively increased participant workload, as assessed by a subjective measure, and by a measure of secondary-task performance on the working memory task. We then examined the effects of task load on other measures of engineer attention and performance. All performance measures were subjected to analyses of variance (ANOVA) to examine the effects of task load.

2.2.1 Subjective Mental Workload

The mean subjective mental workload ratings participants provided at the end of each scenario are shown in Figure 8. The mental workload scores were subjected to a one-way repeated measure ANOVA with task load as the factor with three levels (baseline, low load, high load.) This analysis yielded a significant main effect for task load $F(2,22) = 150.75, p < 0.01$.

¹⁰Bridge Strike Order: A procedure described in the railroads Special Instructions as a safety precaution after the railroad has received a credible report that an undergrade bridge may have been structurally damaged due to an unusual event, such as an impact with vehicular traffic. The procedure requires the train dispatcher to issue a mandatory directive to affected train operators advising them of the location where maximum train speed must be reduced to 5 mph.

Workload scores were lowest in the Baseline condition ($M = 3.67$, $SE = 0.33$) followed by the Low Task Load ($M = 6.50$, $SE = 0.29$) and High Task Load conditions ($M = 9.67$, $SE = 0.19$).

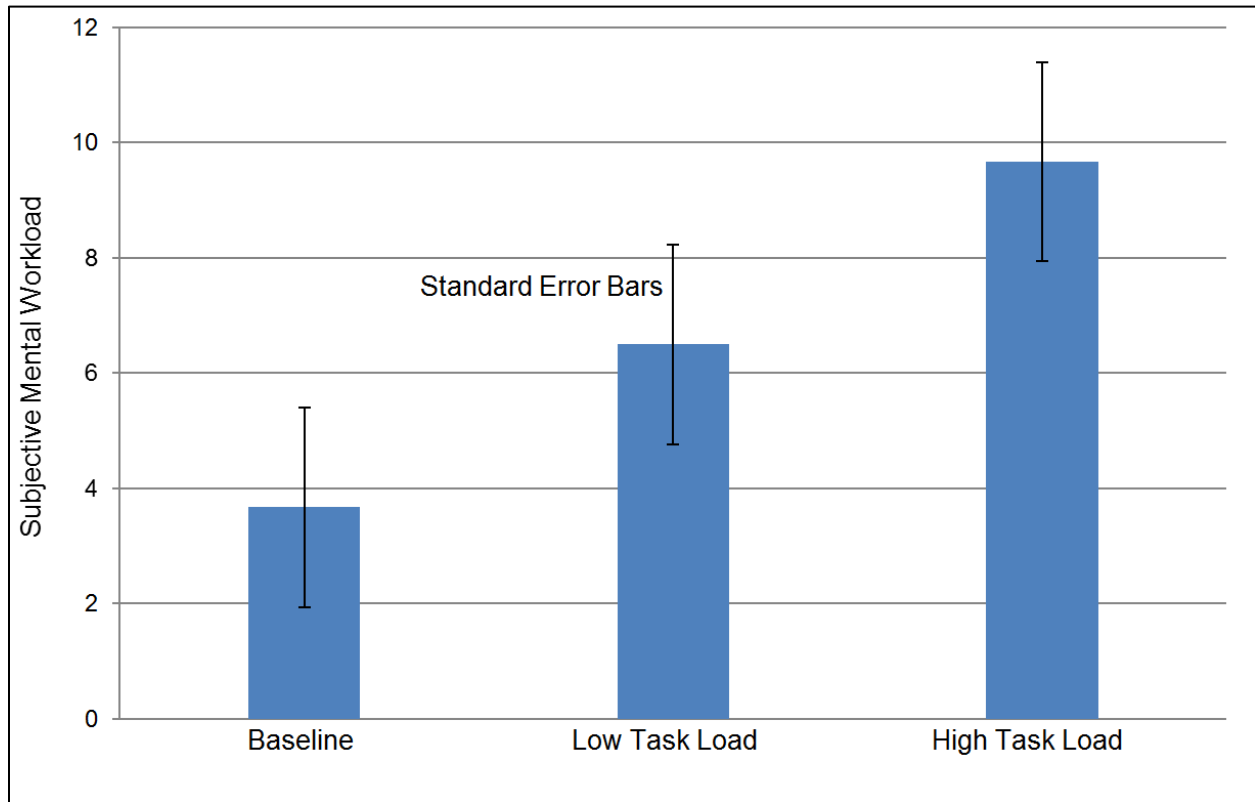


Figure 8. Mean Subjective Mental Workload Ratings Across Task Load Conditions

2.2.2 Objective Mental Workload: Working Memory Performance

Workload ratings provided by participants, while useful, can be subject to biases and individual differences in the way participants view the task. To provide an objective measure of workload we also used a secondary working memory task that was given at four different times in each scenario, as shown in Table 1. Two performance measures were computed from the numbers recalled by participants. The first, free or non-ordered recall, was computed as the percentage of numbers (N) correctly recalled (without respect to order), or Memory performance = $[N/(4*8)]*100$ for the Baseline and Low Task Load conditions, where 8 numbers were presented 4 times. For the High Task Load condition, where 12 letters were presented 4 times, Memory performance = $[N/(4*12)]*100$. The second working memory performance metric, ordered recall, was computed in the same way, except that N was the number of numbers correctly recalled in the right order.

Figure 9 shows the working memory scores in each scenario. The mean percentages of working memory performance were subjected to a 3 X 2 repeated measure ANOVA with factors of task load (Baseline, Low Task Load, High Task Load) and type of recall (ordered or free recall). There were significant main effects for task load $F(2,22) = 24.88$, $p < 0.01$, and type of recall $F(1,11) = 110.22$, $p < 0.01$, but the interaction between the two factors was not significant $F(2,22) = 0.21$. The mean working memory performance percentages for ordered recall were higher in the Baseline and Low Task Load conditions than in the High Task Load conditions

($M = 31.2$, $SE = 2.80$). In addition, mean working memory performance percentages for free recall were also highest in the Low Task Load condition ($M = 80.20$, $SE = 3.61$) followed by the Baseline ($M = 77.62$, $SE = 3.48$) and High Task Load conditions ($M = 56.8$, $SE = 3.69$). Overall, as expected, scores were higher for free recall ($M = 71.81$, $SE = 3.41$) than ordered recall ($M = 45.58$, $SE = 3.52$).

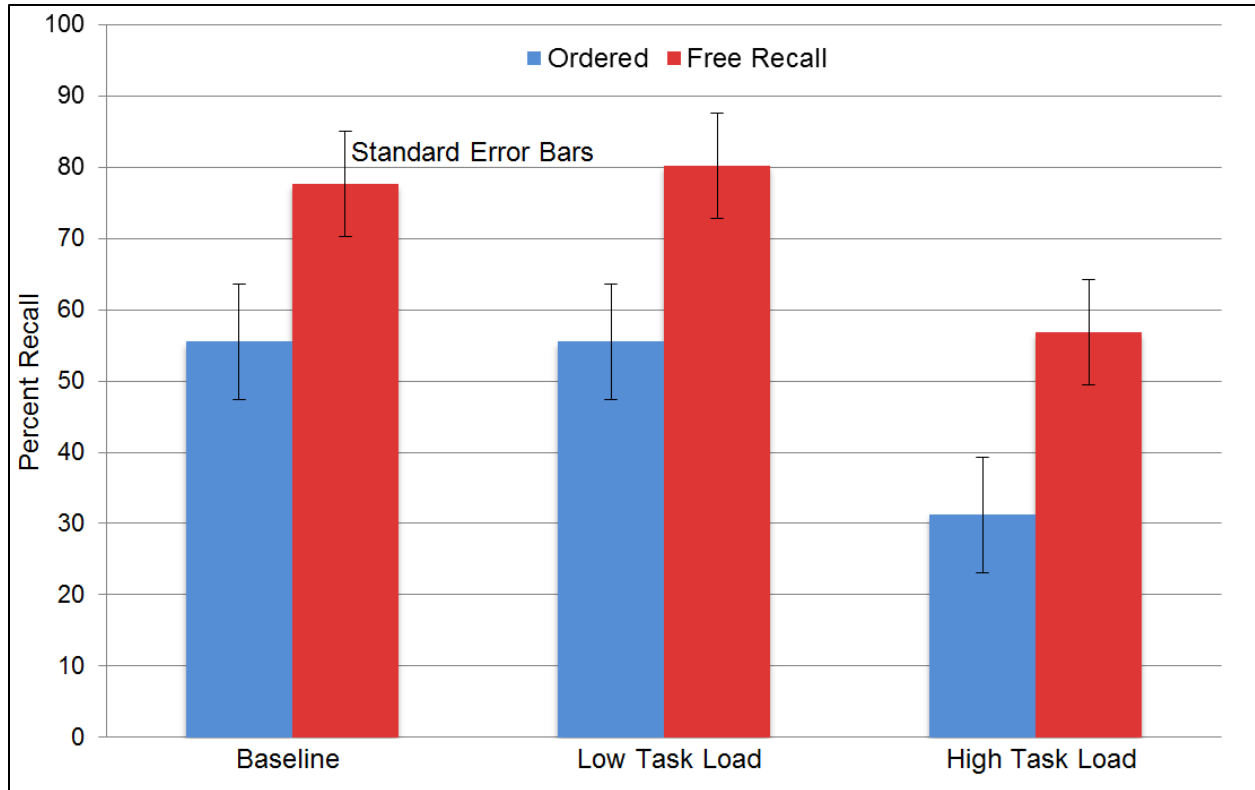


Figure 9. Working Memory Performance: Mean Ordered and Free Recall Percentages Across Task Load Conditions

Having established that the three operational scenarios we developed were indeed associated with progressively increased task load, as assessed using both subjective and objective measures, we then examined the effects of task load on several measures of locomotive engineer attention and performance. These included speed restriction compliance, general rule requirements compliance, reactions to unusual events, and schedule performance.

2.2.3 Permanent Speed Restriction Compliance

As Table 1 indicates, there were four permanent speed restrictions in each of the three scenarios. Compliance was measured by examining locomotive speeds between the associated milepost (MP) markers. If the maximum locomotive speed did not exceed the posted maximum speed + 10% compliance was rated as 1; if the posted speed + 10% speed was exceeded, compliance was rated as 0. For example, if the maximum speed exceeded the posted maximum speed between MP markers MP 185.9 and MP 191.7 (60 mph) by more than 10%—i.e., if speed was greater than 66 mph—compliance was rated as 0; otherwise compliance was rated as 1. The mean compliance scores were then averaged across all permanent speed restriction ranges and scenarios and are shown in Figure 10.

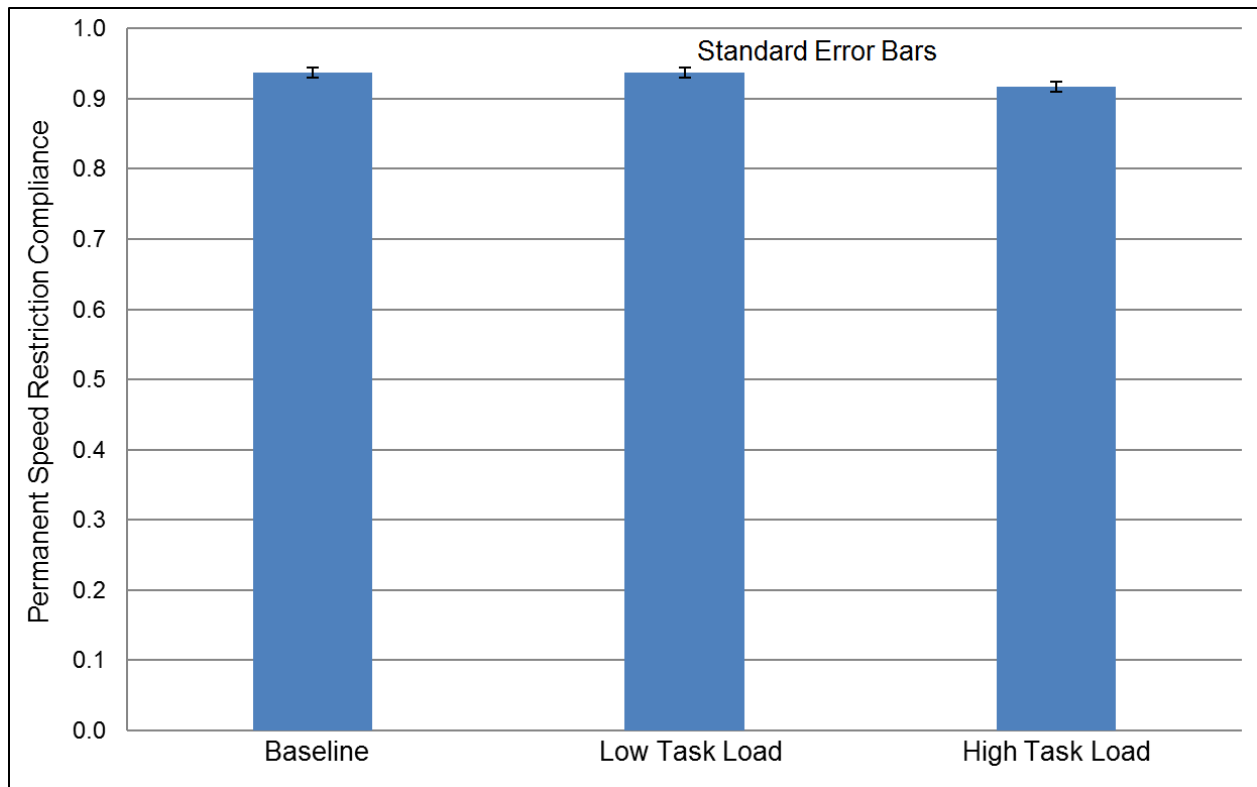


Figure 10. Speed Restriction Compliance: Mean Compliance with Permanent Restrictions Across Task Load Conditions

The mean scores of permanent speed restriction compliance were subjected to a one-way repeated measure ANOVA with task load as the factor with three levels (Baseline, Low Task Load, High Task Load).

There was no significant main effect for task load $F(2,22) = 0.09$, although the lowest compliance was in the High Task Load condition ($M = 0.92$, $SE = 0.04$). As Figure 10 shows, permanent speed compliance was generally high across all three task load scenarios but did not reach the accepted industry standard of 100% compliance given a 10% buffer above the maximum allowed speed.

2.2.4 Temporary Speed Restriction Compliance

As Table 1 indicates, there were two temporary speed restrictions in the Low Task Load condition (scenario 2) and four in the High Task Load condition (scenario 3). Temporary speed restriction compliance was computed in the same manner as for the permanent speed restrictions. For example, if there was a temporary speed restriction of 25 mph between MP markers 199.5 and 200.5 in the Low Task Load condition and the maximum speed exceeded 26.5 mph (25 mph + 10%), compliance was rated as 0; otherwise compliance was rated as 1. The mean compliance scores were then averaged across all temporary speed restriction ranges and scenarios and are shown in Figure 11. Since there were no temporary speed restrictions in the Baseline condition (scenario 1), compliance rates for this condition were set to 1. The mean scores of temporary speed restriction compliance were subjected to a one-way repeated measure ANOVA, which did not yield a significant main effect for task load $F(1,11) = 0.22$, although as Figure 11 shows, the

mean temporary speed restriction compliance was somewhat lower in the High Task Load condition ($M = 0.69$, $SE = 0.08$) than in the Low Task Load condition ($M = 0.75$, $SE = 0.12$).

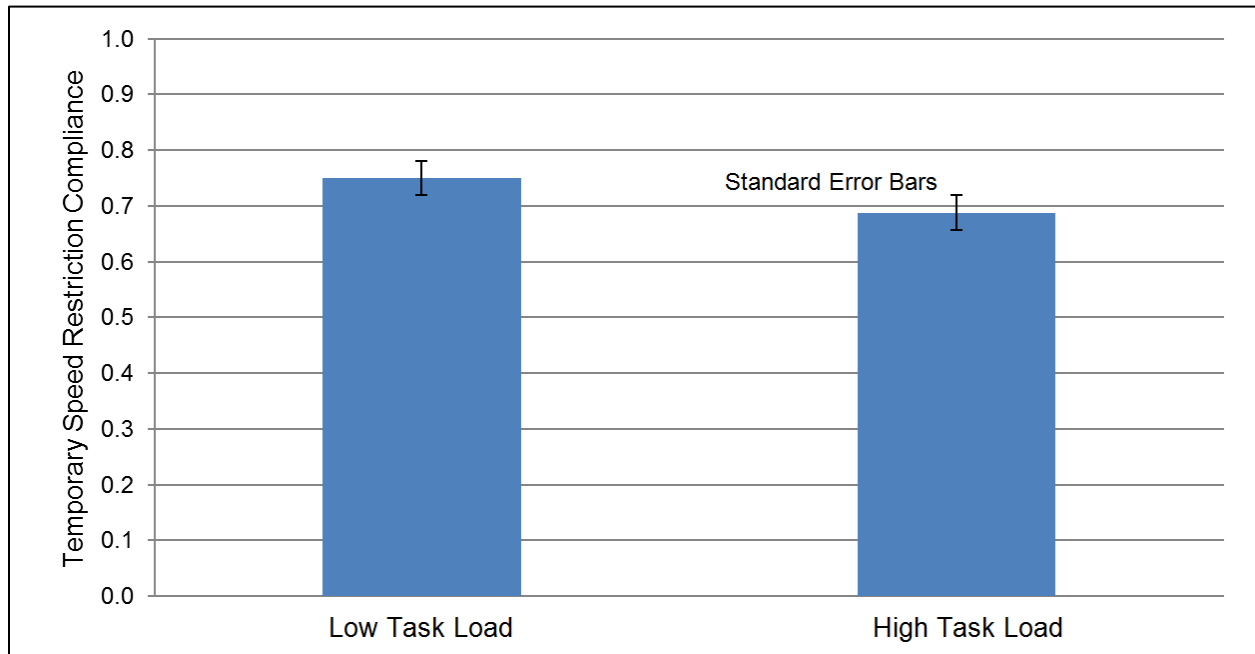


Figure 11. Speed Restriction Compliance: Mean Temporary Speed Restriction Compliance Across Task Load Conditions

2.2.5 Comparison of Permanent and Temporary Speed Restriction Compliance

The temporary and permanent mean speed restriction compliance scores were also subjected to a 2 X 2 repeated measures ANOVA with compliance type (permanent or temporary) and task load (low or high) as factors. As shown in Figure 12, this analysis yielded a significant main effect for compliance type $F(1,11) = 10.00$, $p < 0.01$, indicating that compliance was lower for temporary ($M = 0.69$, $SE = 0.08$) than for permanent speed restrictions ($M = 0.93$, $SE = 0.06$). The main effect for task load $F(1,11) = 0.40$, and the interaction between compliance type and task load were not significant $F(1,11) = 0.07$.

2.3 General Rule Requirement Compliance

2.3.1 Horn Use

The location placement of the five separate highway grade crossings (HGX) was consistent in all three scenarios. The applicable railroad rule requires the locomotive horn to be sounded in a signal-sequence of two longs, a short, and a long, for a minimum of 20 seconds in advance of and until the locomotive has actually occupied the applicable HGX.¹¹ Each test subject locomotive engineer was observed by the principal investigator who recorded either a 1 for compliance, or a 0 for noncompliance. The mean compliance scores were then averaged across all the HGX (Figure 13). The mean horn compliance scores were subjected to a one-way repeated measure ANOVA, which did not yield a significant main effect for task load $F(2,22) = 1.00$, although compliance was lowest in the High Task Load condition.

¹¹49 CFR Part 222.21(b)(2).

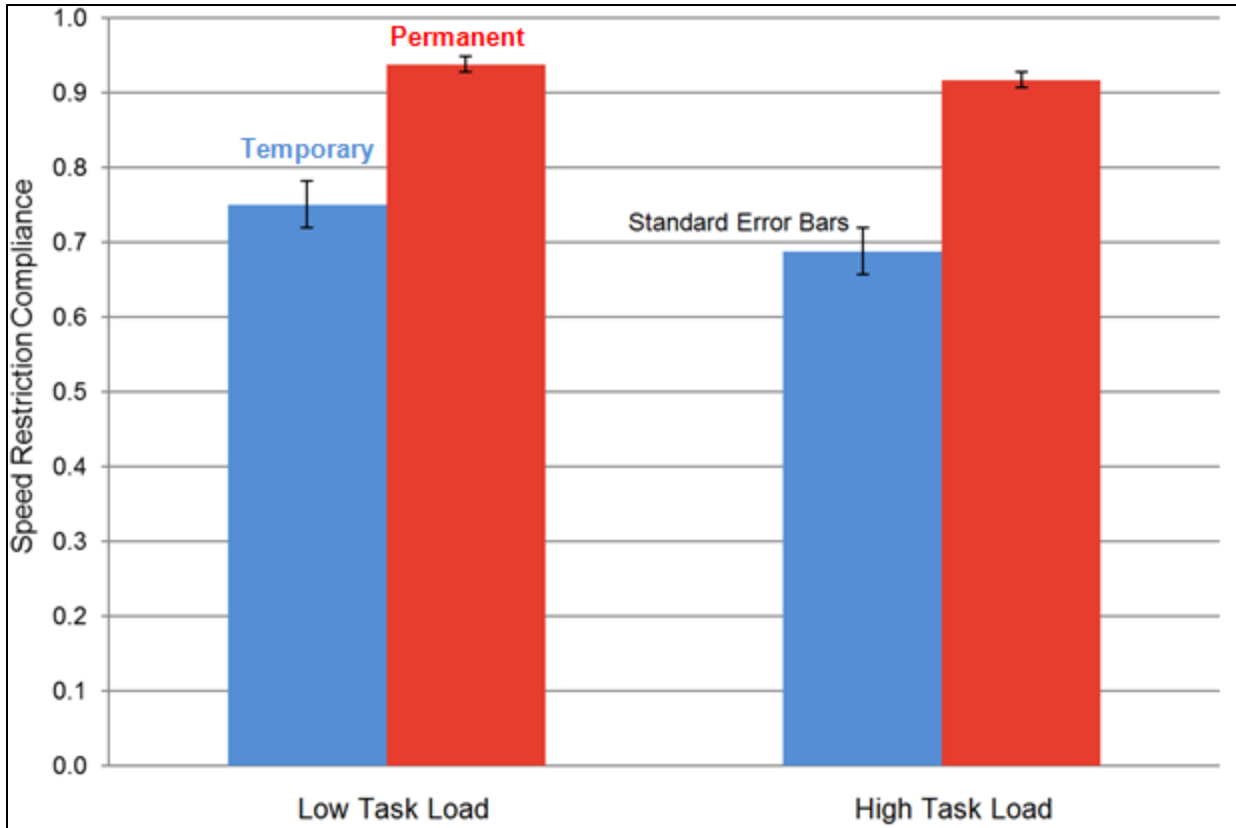


Figure 12. Mean Temporary and Permanent Speed Restriction Compliance Across Task Load Conditions

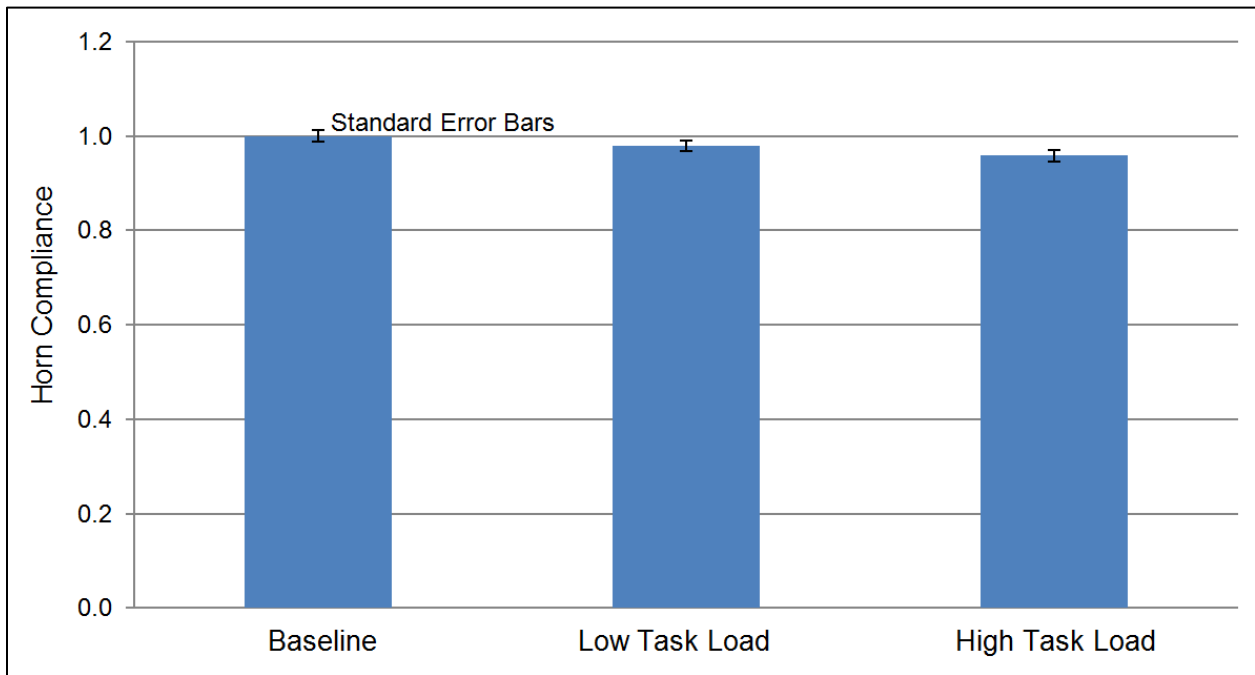


Figure 13. Mean Horn Compliance Across Task Load Conditions

2.3.2 Radio Communication Procedures

Railroad operating rules require the use of radio communication under certain circumstances, and that those communications be transmitted according to specified rule protocols. The location placement of three wayside signals displaying restrictive “approach” (yellow) indications was consistent in all three scenarios. The applicable railroad rule requires the operator to verbally communicate the name and location of restrictive signal indication to a qualified employee on the engine or train as soon as it is visible.¹² Other restrictive signals placed only in scenarios 2 and 3 included:

- Restrictive wayside control signals (yellow aspect, approach indication; red aspect, stop indication)
- Restrictive wayside signage (Yellow/Red [2 miles] prior to a MOW Protect order, Red and Yellow boards)
- Acknowledgement of a wayside defect detector that issues a radio status message.

Other events that required radio communication from the operating crew include notification to the train dispatcher of unusual events such as trespassers on the ROW, vehicles in the foul of the track, signal malfunctions, or transmission failures from wayside defect detectors. The principal investigator observed each locomotive engineer during each instance during the scenario where a radio communication response was required and recorded either a 1 for compliance, or a 0 for non-compliance. The mean compliance scores were then averaged across all the radio communication required during the scenario. The mean scores of radio compliance (Figure 14) were subjected to a one-way repeated measure ANOVA, which yielded a significant main effect for task load $F(2,22) = 9.13, p < 0.01$. Mean radio restriction scores were lowest in the Baseline condition ($M = 0.54, SE = 0.10$), followed by the Low Task Load ($M = 0.81, SE = 0.08$) and High Task Load conditions ($M = 0.94, SE = 0.05$). Because the direction of this effect was in the opposite direction to that expected, we re-examined the compliance scores for the radio procedures that were common to all three scenarios, instead of averaging scores across all procedures, and found that these did not differ across task load.

2.3.3 Unusual Events Compliance

Unusual events for the purpose of this study were defined as unexpected high-consequence emergencies that carry the potential of loss of life or serious property damage. There were no unusual events included in the Baseline scenario, and three each in the Low and High Task Load scenarios, consisting of:

- A wayside signal displaying a GREEN (proceed) indication that drops to RED (stop) on approach
- A vehicle in the foul on the ROW
- A trespasser in the foul on the ROW.

¹²NORAC Rule 94(b)(1). In the scenarios presented to the test participants, they were advised to maintain radio communication with the scenario-based personalities of “qualified on-board crew member,” “train dispatcher,” and various MOW personnel, whose roles were provided by the principal investigator via simulated radio communication.

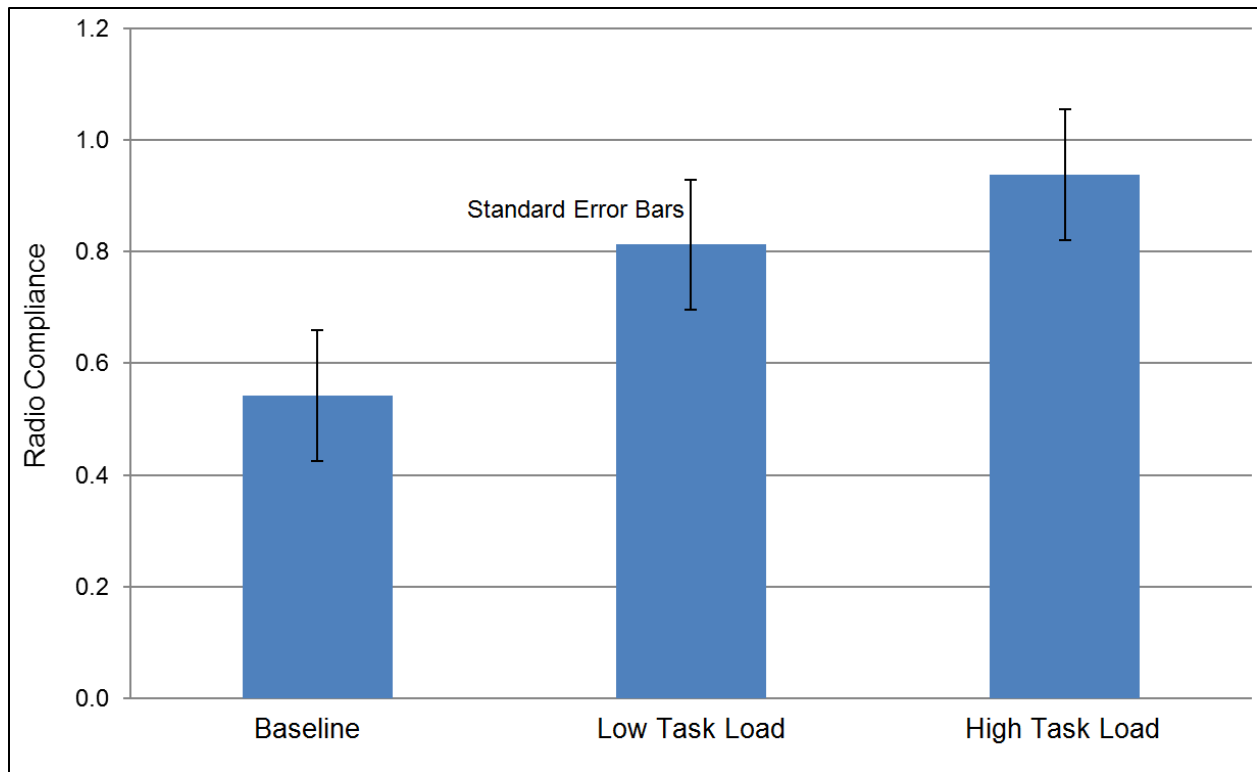


Figure 14. Mean Radio Compliance Across Task Load Conditions

In the case of the signal drop, the test subject compliance consisted of observing and reacting to the signal displayed by safely bringing the train to a stop (mandatory). In the case of the vehicle and trespasser in the ROW, the test subject compliance consisted of observing and reacting to the event by slowing or stopping train movement (mandatory). The principal investigator observed each locomotive engineer during each instance during the scenario where a radio communication¹³ response was required and recorded either a 1 for compliance, or a 0 for non-compliance. The mean compliance scores were then averaged across all the radio communication required during the scenario. The unusual events mean compliance scores (Figure 15) were subjected to a one-way repeated measure ANOVA, which did not yield a significant main effect for task load $F(1,11) = 0.26$, although the mean compliance scores for unusual events were higher for the Low Task Load condition ($M = 0.79$, $SE = 0.11$) compared to the High Task Load condition ($M = 0.72$, $SE = 0.10$).

¹³Train operators are required to report all anomalies, equipment failures, and/or unusual conditions to the train dispatcher.

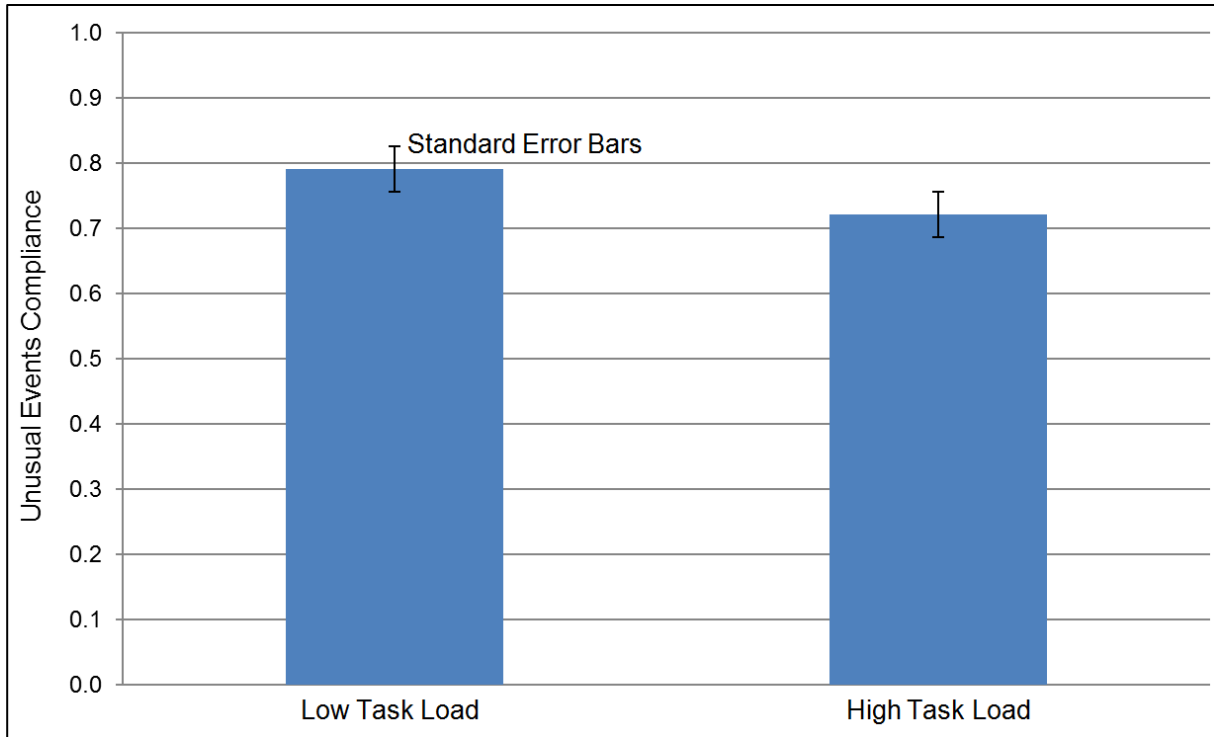


Figure 15. Mean Unusual Events Compliance Scores Across Low and High Task Load Conditions

2.4 Discussion

Study I examined the effects of a variation in operational task load over three levels on different aspects of locomotive engineer performance. Both objective and subjective measures provided validation that the three simulated scenarios we developed were indeed graded in task load and operational difficulty. The participant locomotive engineers unanimously and progressively rated the Low Task Load scenario as leading to significantly greater subjective mental workload than the Baseline scenario, and the High Task Load scenario to even greater workload. The objective secondary working memory task data generally provided results consistent with the subjective measures. Although there was no difference in working memory scores between the Baseline and Low Task Load conditions, there was a significant and marked reduction in working memory performance in the High Task Load condition. This finding also validates the use of the secondary task method as an objective technique for assessing the mental workload associated with a primary task [9].

Having established that the three scenarios were associated with progressively higher levels of mental workload, we examined the effects of task load on other aspects of engineer performance. With respect to compliance with speed restrictions, we found that compliance with temporary speed restrictions was significantly lower than for permanent ones, although compliance rates for both types did not reach 100%. A survey of railroad industry operating managers revealed that given a 10% buffer over the posted maximum speed limit, 100% compliance is expected of

locomotive engineers.¹⁴ Instead in the present study we found compliance rates of about 92% for permanent restrictions and about 70% for temporary restrictions. There was no statistically significant effect of task load on these compliance rates, probably reflecting the relatively small sample size of participants. Nevertheless, mean speed compliance rates were lowest in the High Task Load condition. The results for compliance are also consistent with previous related work. Analyses of “close calls” in rail operations have shown that temporary restrictions are a much bigger problem than permanent ones [10].

We assessed two aspects of general rule requirements compliance, horn usage and radio procedure. The results for horn usage were similar to those for permanent speed restriction compliance: high, but not 100%, and while there was no statistically significant effect for task load, compliance was lowest in the High Task Load condition. For radio compliance, there appeared to be a statistically significant effect of task load, but in the opposite direction to that expected. Compliance was greatest in the High Task Load condition, intermediate in the Low Task Load condition, and lowest in the Baseline condition. However, upon further analysis involving only the comparison of the radio compliance events common to all three scenarios, there appeared to be no statistically significant differentiation, countering the initially observed disparity resulting from combining scores from all events.

Test participants were exposed repeatedly, during the course of operating over all three scenarios, to the common radio compliance events consistently displayed during each scenario, enabling them to develop a certain “compliance memory,” which provided an objective basis for analysis of those “common” events in comparison to the unusual events presented separately in scenarios 2 and 3. Those radio compliance events *not* consistently presented in all three scenarios (i.e., in scenarios 2 and 3), involved “unusual” situations (e.g., trespassers, signal malfunctions) which may have caused test participants to become “hyper-vigilant” as a result of compensating for the absence of an imprinted “compliance memory” of the event, resulting in a higher rate of compliance than expected under the increased distraction scenarios.

With respect to reactions to unusual events, compliance rates were again less than 100%, averaging 79% for the Low Task Load condition and 72% for the High Task Load condition. Although there was again no statistically significant effect of task load, the low compliance rate for the High Task Load condition provides evidence that this condition was especially effective in reducing attentional performance on the part of the engineers.

¹⁴49 CFR Part 240.305(a)(1) provides a more lenient standard for regulatory speed compliance than the 10% buffer used for data analysis in this study, “[It shall be unlawful to;] Operate a locomotive or train at a speed that exceeds the maximum authorized speed by at least 10 miles per hour or by more than one half of the authorized speed, whichever is less.” Nonetheless, it was the consensus of opinion from the railroad operating managers polled that the expectation for speed compliance is 100% even in consideration of the study’s stricter buffer of 10%.

3. Study II

3.1 Introduction

The purpose of Study II was to evaluate the effects of sustained attention training which may potentially reduce the effects of distraction on locomotive engineer performance in commuter rail traffic and thereby enhance the safety of such operations. In Study I of this project, we developed and validated operating scenarios for assessing effects of distraction using the U.S. Federal Railroad Administration sponsored Cab Technology Integration Laboratory (CTIL). The results of that study showed that the scenarios were effective in simulating real-life situations as well as in creating operator distraction by means of task-load variation, thus providing a suitable foundation for evaluating distraction effects on operator performance. The design of the operating scenarios created and refined in Study I served as the foundation to create the scenarios to be used in Study II. Study I scenario development provided sufficient validation of the effectiveness of a variety of distraction elements on operators performance, enabling the research team to create two discrete operating scenarios-one *low distraction* one *high distraction*.

While distraction is a normal part of human behavior and stems from various failures of attention [11], it is not inevitable and can be mitigated in different ways, including workplace design and training of human operators. Given that there are limited opportunities to change the design of current locomotive cabs and operational procedures, we focused on training in Study II of this project, specifically attention training. There is a large and growing research literature testifying to the positive effects of attention and mindfulness training on reducing distraction in healthy adults [12].

Although it was once thought that many mental abilities such as attention and working memory are fixed traits of a given individual, recent research has established that these functions are malleable and can be improved with extensive training [13]. For example, Jaeggi and colleagues [14] had participants train on a demanding dual verbal-spatial working memory task for half an hour each day for 8, 12, 17 or 19 days. They found that compared to a control group, the trained group showed significant gains not only in working memory capacity, but also in a test of general cognitive ability that was not trained on. Furthermore, they found that the extent of the gain was dependent on the amount of training, with the greatest benefit being found for individuals who received 19 days of training. Another study by Sohlberg and Mateer [15] found that 5 to 10 weeks of training led to significant improvement in attentional performance in a group of patients with brain injury. Such performance gains are also accompanied by changes in brain structure and function, as revealed by magnetic resonance imaging (MRI) studies [16]. Although more recent research findings have led to a debate as to whether specific forms of training, like attention or working memory training, transfers to general cognitive ability [17], there is little doubt that prolonged training improves attentional performance [18].

In Study II we examined whether a relatively short period of training could reduce distraction-related errors of the type found in Study I. The underlying premise was that, compared to a control group, locomotive engineers exposed to a Sustained Attention Training (SAT) would exhibit fewer attention-related errors as compared to a control group who were not exposed to SAT.

3.2 Methods and Testing

3.2.1 Participants

A total of 24 Massachusetts Bay Commuter Railroad (MBCR) locomotive engineer volunteers participated in the study. They were aged 23-67 years (23 male, 1 female, mean 42 years, standard deviation 11) and had between 4 and 38 years of operational experience (mean 14.29 years, standard deviation 10.37). The only qualifying criterion for the volunteers was that they be currently licensed locomotive engineers.¹⁵ Participants were randomly assigned to either a Sustained Attention Training or SAT (N=12) group or a control group (N=12). (Details of the SAT and control group training are provided in Section 3.1.4). The duration of time required to complete the experimental protocols established for Study II required a full 8 to 10 hour day for each of the 24 participants with a testing timeline as follows:

- 08:00 - 08:30: Participant arrives at Volpe, is processed through security, issued credentials and escorted to the training room, introduced to Volpe personnel, the chief investigator and locomotive engineer CTIL-operation subject matter expert, and provided with an orientation with facility amenities, and safety briefing.
- 08:30 – 11:30: Training is administered to participant using one of two training modules in a classroom setting.
- 11:30 – 12:30: Participant is escorted across the Volpe campus to the CTIL lab, provided with a tour of Building 6 lab facilities, orientation with facility amenities. Experimental liability release, survey, and administrative documents collected; orientation scripting read, thorough technical job briefing conducted concerning operating territory engineering line chart, timetable, permanent speed restrictions, rules in effect and special instructions.
- 12:30 – 13:00: Participant is allowed to operate the CTIL Baseline scenario for 30 minutes with assistance from the locomotive engineer CTIL-operation subject matter expert in order to gain an understanding of the operational characteristics of the equipment in relationship to the animated operational scenarios.
- 13:00 – 13:30: Catered lunch break.
- 13:30 – 15:00: Participant receives operating paperwork necessary to operate Study II scenario 2 or 3 from Shady Grove to Cicero,¹⁶ and is isolated within the CTIL confines. Participant responds to operating direction from the Train Dispatcher via simulated radio communication, proceeding until the conclusion of the scenario when the train arrives at Cicero.
- 15:00 – 16:30: Participant receives operating paperwork necessary to operate final Study II scenario from Shady Grove to Cicero. Participant is isolated within the CTIL confines, proceeding until the conclusion of the scenario when the train arrives at Cicero.
- 16:30 – 17:00: Participant is debriefed, interviewed and released.

¹⁵Per Title 49 Code of Federal Regulations Part 240.

¹⁶The order of the scenarios presented to the test subjects in Study II was selected at random, but all test subjects operated over both Scenario 2 and Scenario 3.

3.2.2 Cab Technology Integration Laboratory (CTIL)

The CTIL is a tool that enables research to: (1) demonstrate and assess the human machine-interface (HMI) of new technologies, prototype workstations configurations and examine operating procedures by evaluating human performance, and; (2) help reduce the risk of human errors by identifying potential HMI system and operational weaknesses and developing improvements in system design, training, and/or procedures to address those risks. The full CTIL facility includes a physical locomotive cab with standard displays and controls, out-of-the-window displays of naturalistic scenes provided by a dedicated computer with a powerful graphics engine, software for scenario development, execution, and full data capture, including both locomotive and engineer performance parameters. In-cab and out-of-the-window views of the CTIL are shown in more detail in Figures 16, 17, and 18.



Figure 16. Cab Technology Integration Lab (CTIL)

Note that the CTIL software was changed between Studies I and II, hence there are slight differences in these scene presentations or views. Designed as a research simulator-laboratory, the Cab Technology Integration Lab (CTIL) simulation and modeling software was converted to CORYS so as to be consistent with most industry locomotive training simulators with respect to fidelity and representation of current locomotive systems, displays, controls and handling characteristics. The primary simulation and modeling system software, the software containing the mathematical models of the train physical behavior in the simulator, among other functions, was made compatible with that operated by many railroads for two important reasons: (1) having an industry matching simulation system gives the CTIL the capability to run real-world track profiles of thousands of miles of track developed by the railroads for training purposes. These profiles contain GPS and elevation data to accurately depict track routes. The scene presentation for Study II utilized one such route profile which was different, although similar, to the route used in Study I. As other research is conducted, these track profiles would not have to be recreated for use as the test scenarios in the simulator, which saves thousands of dollars in software development costs and (2) railroad industry compatible software can readily enable cooperation in research and development activities with the rail operating community and results

obtained from research in CTIL would be more readily generalizable because of the fidelity of the test conditions that could be configured as a result of the change in the simulation and modeling software for the CTIL.



Figure 17. Inside View of CTIL Cab



Figure 18. Example of Outside View from CTIL Cab

3.2.3 Scenarios

The scenarios involved the simulated operation of a typical commuter train similar to those operated by the test participants on the MBCR, consisting of one-SD-40 locomotive pulling five coaches operating over the Chicago line from MP 46 (Shady Grove) to MP 7.0 (Cicero, IL), a total distance of 39.0 miles. The operating scenarios used in Study II had to be reprogrammed as a result of software failures in the programs that supported the MBCR Providence Line scenarios used during Study I. While there were slight variations in the scenery and various landmarks (e.g., location/ numbers of Highway-rail grade crossings, bridges, passenger station names, etc.) between the Study I scenarios and the scenarios created for Study II, the railroad operational characteristics (e.g., method of operation, operating rules/special instructions, maximum operating speed, use of temporary restrictions for speed and MOW work, etc.) between the two were identical.

The method of operation was by a centralized Train Control System (TCS), under the direction of a train dispatcher, supplemented in the field by Automatic Block System (ABS) of wayside signals. The scenarios were displayed on full-panel flat-screen monitors in both forward facing windshields of the CTIL as well as side-window views for both sides of the cab. A one-hour continuous audio loop of recorded railroad radio transmission-traffic between various train dispatchers, operating crews and railroad wayside personnel played continuously in the background of the CTIL, simulating a realistic field operational environment.

The experimenter was located remotely in a separate control room and had direct visual/audio observation of each test subject operating the CTIL via in-board cameras and microphones. The experimenter also performed the roles¹⁷ of the virtual train dispatcher, on-board crewmember, and wayside employee(s), providing normal and essential operating information and mandatory directives via simulated 2-way radio communication with the test-subject operator. The experimenter closely followed designated scripts recreated for each of the newly created scenarios, detailing communications initiated by the operator/locomotive engineer, virtual train dispatcher, field personnel or on-board crewmember; as well as the expected responses. All video, audio and CTIL control functions were recorded.

Participants were required to comply with the current railroad operating rules that they were familiar with concerning operating authority, track bulletins in effect, restrictions, radio and emergency procedures.¹⁸ Additionally, operators were briefed prior to the start of the study on operational paperwork, rules in effect, procedures for memory tests (described later), and the need to perform their job functions in the CTIL in the same manner they normally would on the job.

For all scenarios, engineers were provided with a hard-copy timetable of the territory that depicted the location of all passenger stations, interlockings and Highway Grade Crossings (HGX), as well as the maximum authorized train speed along the entire territory, special

¹⁷The experimenter had extensive experience as a railroad train dispatcher and engineering employee.

¹⁸Northeast Operating Rules Advisory Committee (NORAC) Operating Rules 10th edition, effective November 6, 2011; MBCR Special Instructions & Safety Rules; Fictitious timetable, Special Bulletin and temporary speed restrictions (TSRB) based on NORAC/MBCR standards were adapted to the Chicago Sub scenarios.

instructions and published timetable schedule departure times. The operators were also provided with a hard copy of operating authority that described any temporary speed restrictions, work and equipment protection orders, and other track bulletins in effect.

3.2.4 Sustained Attention Training (SAT)

Prior to arriving at the CTIL laboratory on their testing day, each participant was randomly assigned to either a control or training group. Participants in the training group received three hours of Sustained Attention Training (SAT) immediately before operating the CTIL over the two data-collection scenarios. The SAT consisted of video presentations, a slide deck, and oral lecture and discussion presented in a one-on-one fashion by the principal investigator in a classroom setting. The intention of the SAT training was to provide the participants with a rudimentary foundation for understanding of the science of attention, including the associated cognitive strengths and weaknesses inherent to all individuals.

Participants were first instructed that all human behavior is a product of two underlying processes, an automatic (or habitual) process that is largely unconscious, and a controlled (or effortful) process that represents a limited resource (Figure 19). They were instructed, using real-life examples, that various factors impact on this limited attentional resource: these include task overload /underload, expectation bias, mental rumination, and mind wandering (Figure 20).

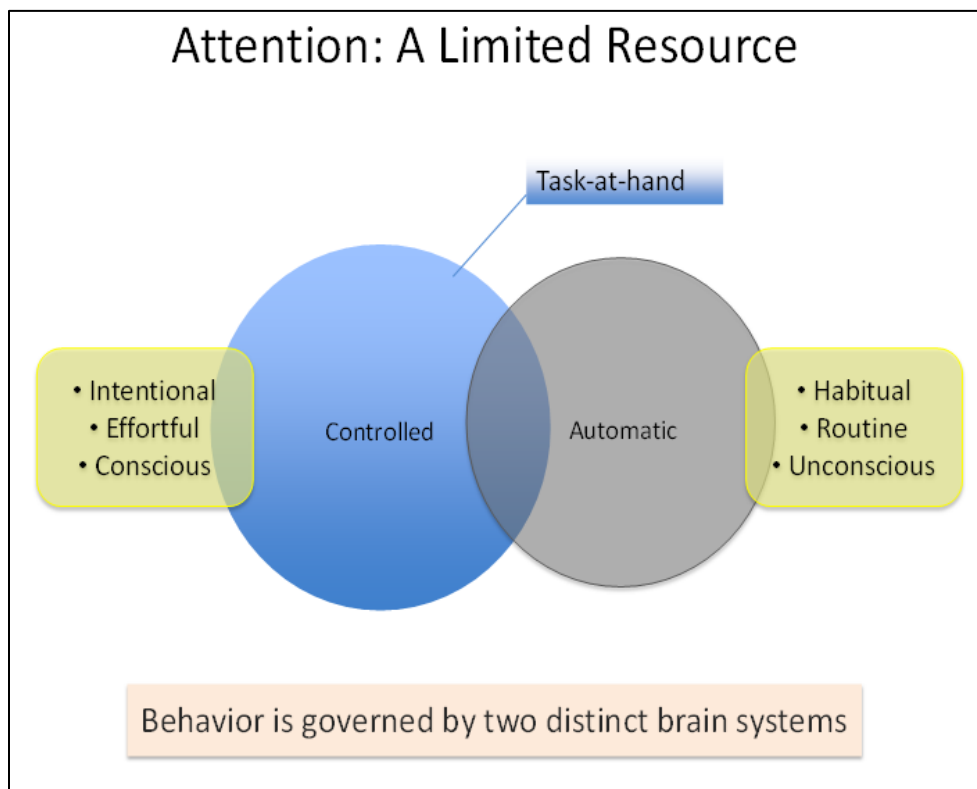


Figure 19. Automatic and Controlled Attentional Processes

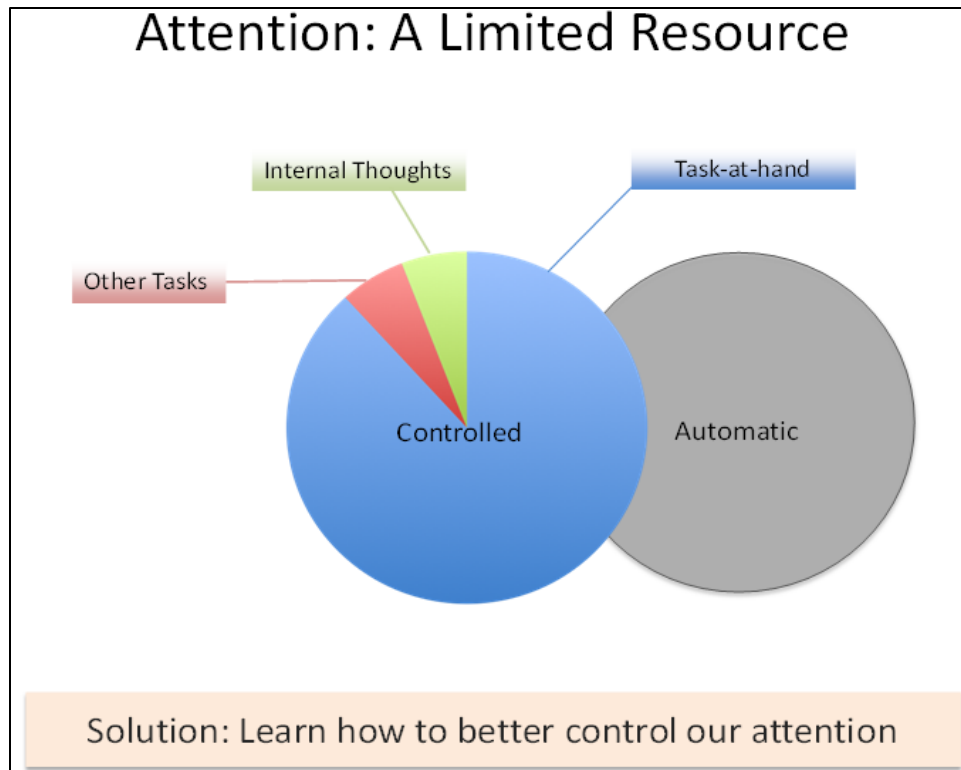


Figure 20. Controlled Attention Is a Limited Resource

An emphasis on the finite limitations of the conscious control system was provided [19], so that participants could see how depleting attention resources can lead to attention-related errors (Figure 20). With each major concept presented, the instructor solicited feedback from the test subject, provided real-life examples acquired through research and investigations, and utilized a variety of instructional aids including instructional video shorts depicting actual events from inboard cameras in locomotives, busses and light-rail transit vehicles, as well as other video shorts from YouTube and other sources demonstrating a variety of discussed principles.

The role of knowledge and expectations in shaping behavior was also covered as depicted in Figure 21, along with illustrative anecdotes and real life examples anyone can relate to such as driving your automobile along a familiar route on “autopilot” by means of the automatic system.

Midway through the SAT, the instructor provided an introduction to a 20-minute instructional video produced by Veolia for use in Sustained Attention Training (Figure 22). The video featured a psychologist and university professor, as well as Veolia safety investigators who explained the concepts already covered in the SAT, but detailed in more of a real-life context.

The video includes a reenactment of an actual red-signal attention-related error that occurred on a Veolia property and was investigated in detail. Viewers typically found the reenactment very entertaining and informative as it provided a connection to reality that participants were able to relate to.

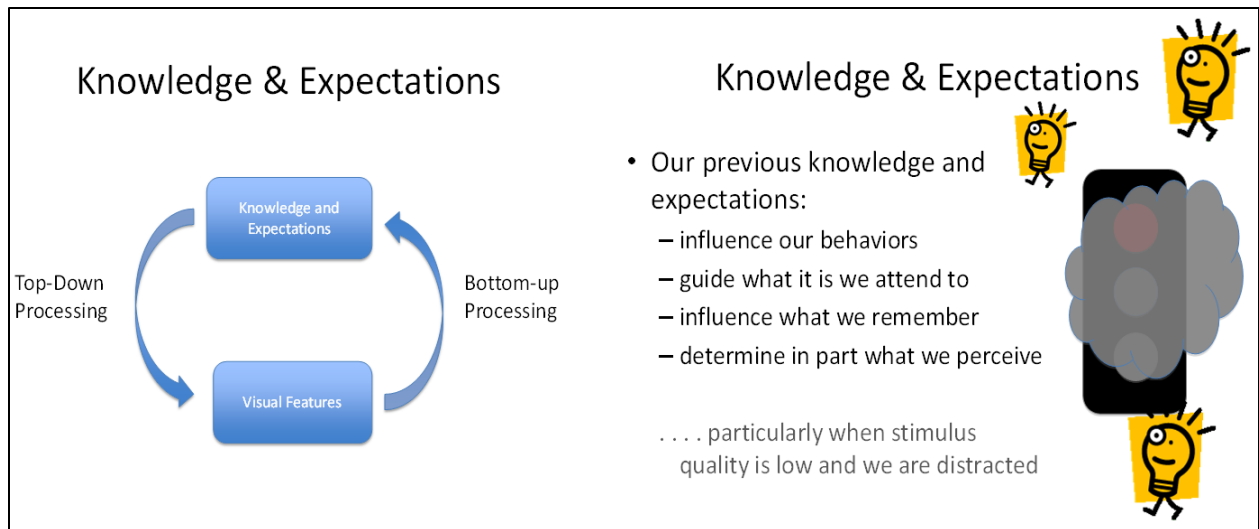


Figure 21. Knowledge and Expectations and Their Influence on Behavior



Figure 22. Video Presentation on a Red Signal Violation

Participants were then instructed about the myth of “multi-tasking.” Figure 23 shows typical data from studies of the effects of multi-tasking on automobile driving performance. When given a secondary memory task while driving, individuals typically have longer brake reaction times and make more memory errors than when they drive without the secondary task [20]. Furthermore, although many people believe that they are immune to the effects of multi-tasking, research shows (see Figure 24), that only a small percentage of people are unaffected by a secondary task while driving.

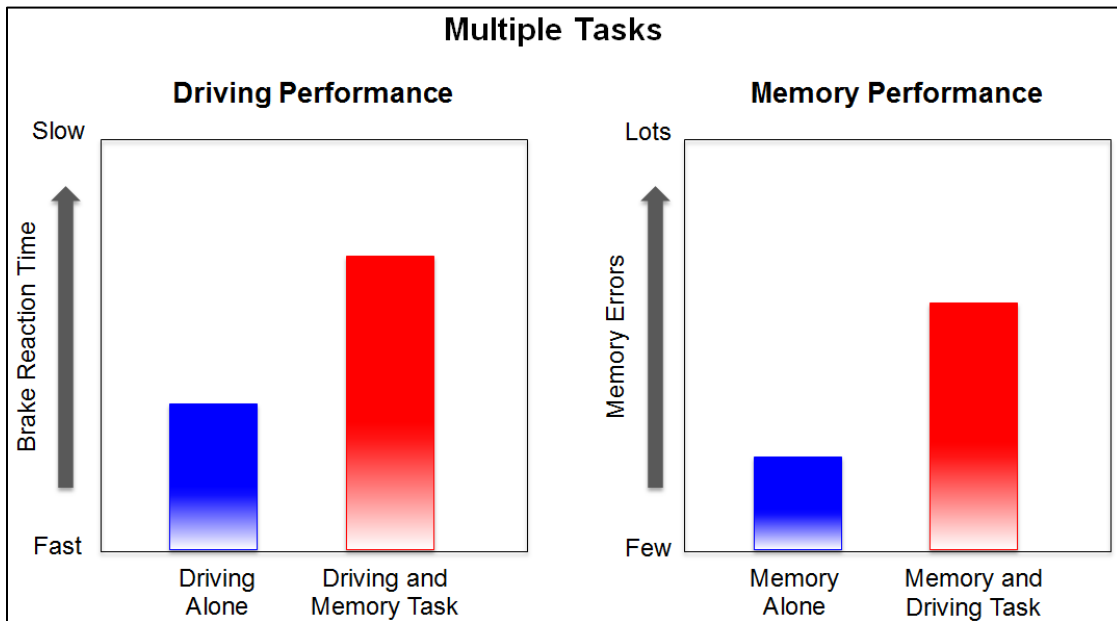


Figure 23. Effects of Multi-Tasking on Driving Performance

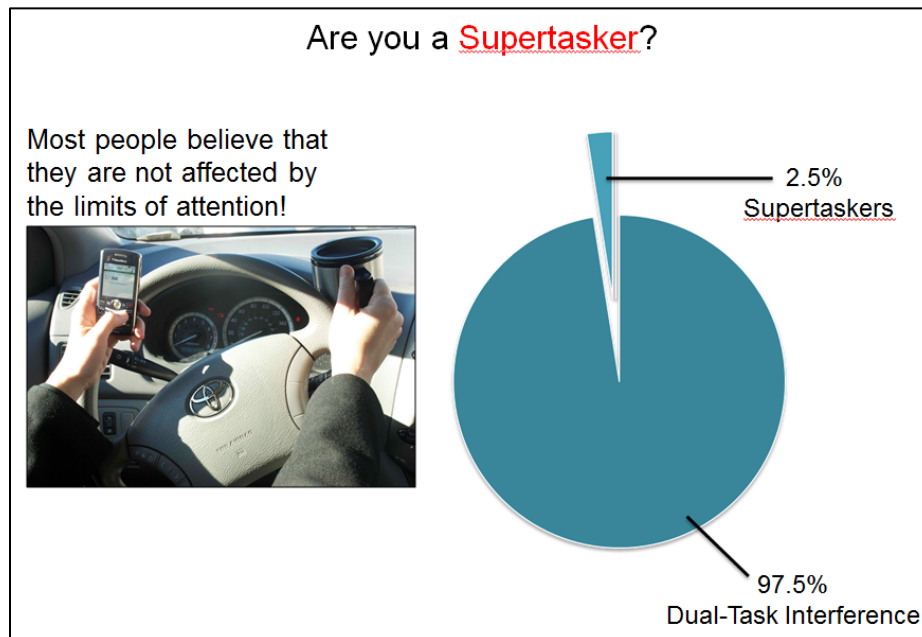


Figure 24. Proportion of People Who Show Dual-Task Interference While Driving

The role that mind-wandering, mental rumination and task under-utilization play in contributing to loss of attention was also covered (Figure 25). The instructor wrapped up the training session by soliciting from the test subject any “sustained attention” strategies they personally use to maintain their focus on the “task at hand,” which would be shared with a larger group.

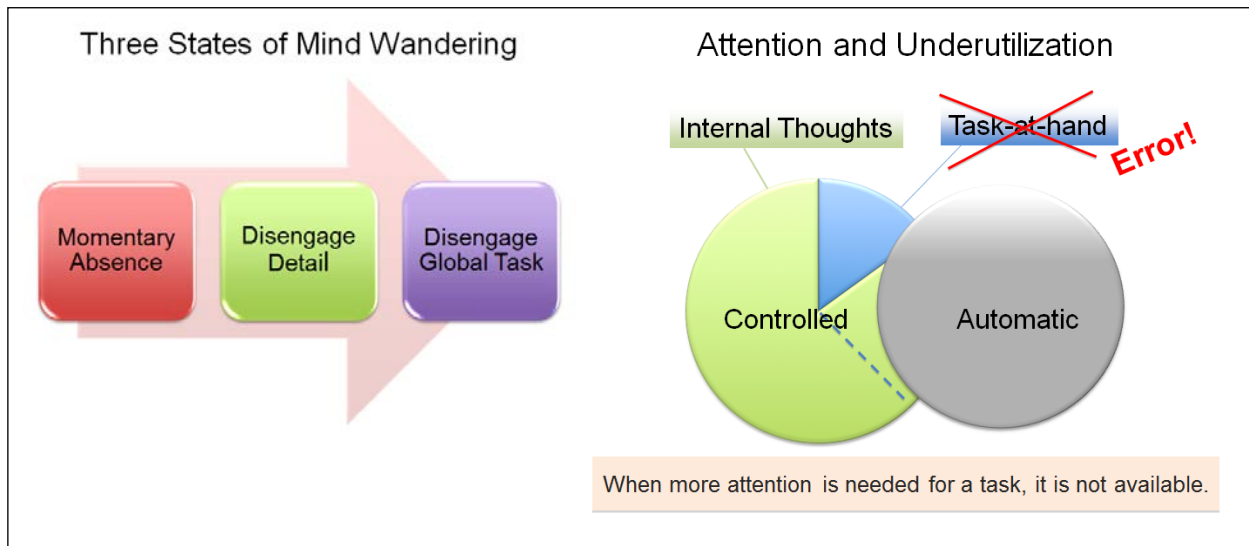


Figure 25. Mind-Wandering and Mental Rumination

Finally, the instructor introduced participants to the concept of developing a “Personal Mindfulness Daily Practice,” a form of “Mind Fitness Training” (M-Fit) currently used by U.S. Marine Corps troops. Participants were shown an 8-minute animated YouTube video explaining the M-Fit process and benefits, and provided with information for further personal research on their own. Each training subject completed a multiple choice test at the conclusion of the training.

3.2.5 Crew Resource Management Training

Each participant in the control group completed 1 hour of Crew Resource Management training (CRM) that was structured in the same multimedia/lecture style as the SAT, and presented on a one-on-one basis by the principal investigator serving as instructor.

The CRM training did not cover any of the specific topics covered during SAT, but focused on enhancing communication and teamwork by means of utilizing detailed job briefing processes and the synergistic resources of all members of a work group. A history of CRM was outlined, covering its evolution from the aviation industry in the 1970’s up to its near universal application in many occupational domains (Figure 26).

As with SAT, the instructor provided real-life examples acquired through research and investigations, and utilized a variety of instructional aids including instructional video shorts depicting actual events from inboard cameras in locomotives, busses and light-rail transit vehicles, as well as other video shorts from YouTube and other sources demonstrating a variety of discussed principles. An 11-minute Veolia-produced re-enactment video of an actual near-miss event emphasized the importance of an effective CRM job briefing and interpersonal communication within a workgroup (Figure 27).

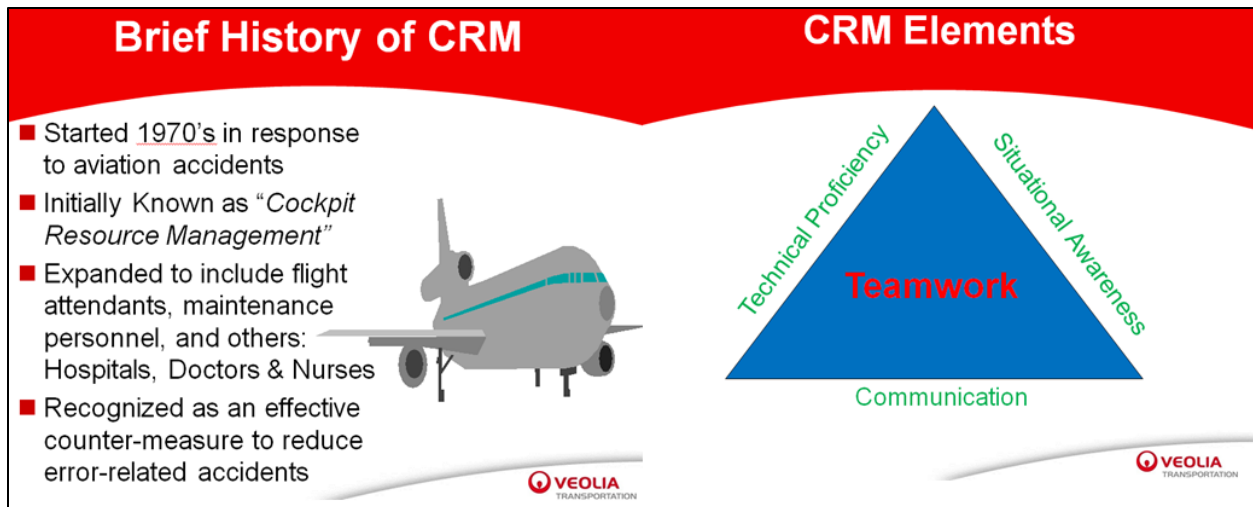


Figure 26. Principles of Crew Resource Management (CRM)

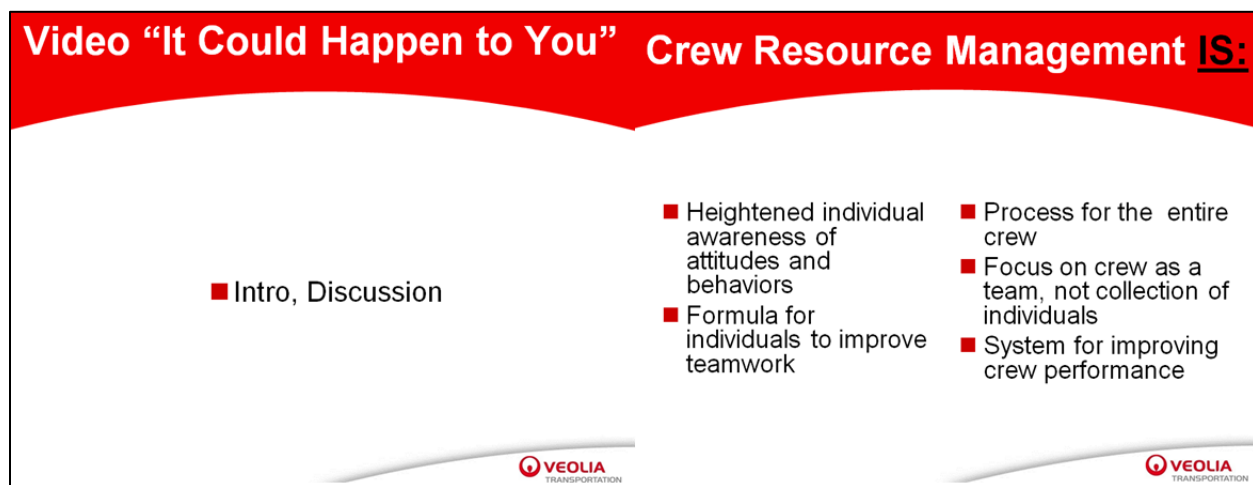


Figure 27. CRM Video

Finally, the instructor provides a recap of CRM principles and findings and application to locomotive operations. At the conclusion of the training, each participant completed a multiple choice test on the training.

3.2.6 Procedures

In all scenarios, engineers were also periodically asked to perform a short working memory task requiring them to report back, after a short delay, numbers that were read out to them by the experimenter. The task is described in more detail below. The rationale for using this task was to simulate the effects of other internal or external sources of distraction that engineers may be prone to experience, as well as to have another performance measure that may be sensitive to task difficulty.

As mentioned previously, each of the scenarios developed was designed to have common task elements, but also additional task elements that made Scenario 2 more challenging than Scenario 1, and Scenario 3 in turn more challenging than Scenario 2. However, as a result of the analysis of participant data collected during Study I, particularly the effects of three levels of task load,

the investigative team concluded that there was not a measureable significance between the events common to all three scenarios (i.e., permanent speed compliance, General Rule Compliance and 8-number working memory task). It was also noted that all participants scored the Baseline Scenario 1 as least challenging as compared to Scenarios 2 and 3. Consequently, the investigative team concluded that the diminished value of information collected from test participants operating over the Baseline Scenario 1 in Study I, would not justify an additional Baseline Scenario data collection during Study II.

3.2.7 Task load Elements Common to the Low Task Load (Scenario 2) and High Task Load (Scenario 3)

Both scenarios (2 and 3) were formatted over the same 39-mile animation section of the Chicago line beginning at MP 46 and proceeding eastward to MP 7. All test subject data collection sessions started at MP 46 and ended at MP 7.0. Both scenarios included the following routine operational elements common to most commuter rail operations (as summarized in Table 2).

Table 2. Summary of Task Elements Present in Scenarios 2 and 3

Task Elements	Low Task Load (Scenario 2)	High Task Load (Scenario 3)
Permanent Speed Restrictions	MP 38.0 – 38.1: 35 mph MP 38.4 – 38.0: 35 mph (XOVER) MP 38.1 – 35.0: 55 mph MP 35.7 – 35.6: 35 mph (XOVER) MP 35.0 – 7.0: 70 mph MP 28.3 – 28.1: 35 mph (XOVER) MP 9.6 – 9.4: 35 mph (XOVER)	MP 38.0 – 38.1: 35 mph MP 38.4 – 38.0: 35 mph (XOVER) MP 38.1 – 35.0: 55 mph MP 35.7 – 35.6: 35 mph (XOVER) MP 35.0 – 7.0: 70 mph MP 28.3 – 28.1: 35 mph (XOVER) MP 9.6 – 9.4: 35 mph (XOVER)
Working Memory Task	8 numbers: Presented at MP 45.0, 37.0, 17.5, and 9.0	12 numbers: Presented at MP 45.0, 37.0, 17.5, and 9.0
Temporary Speed Restrictions	MP 37.5 – 37.0: 30 mph MP 24.5 – 24.0: 30 mph	MP 43.5 – 43.4: 20 mph MP 37.5 – 37.0: 30 mph MP 24.5 – 24.0: 30 mph MP 16.9 – 16.8: 20 mph
General Rule Requirements	Horn Use Compliance (20) Radio Compliance (13)	Horn Use Compliance (21) Radio Compliance (18)
Unusual Events	MP 33.6: Signal Malfunction Control Signal Dropped to Red MP 16.8 Vehicle in foul Hinsdale Road MP 11.5 Trespasser on ROW	MP 27.2 HBD (no announcement from detector) MP 18.3 Vehicle in ROW MP 12.0 Trespasser in ROW MP 11.5 Signal Malfunction Control Signal Dropped to Red

Operational Elements Included in Scenarios 2 and 3

- Maximum Operating Speed (Unless otherwise restricted) 79 mph

Three permanent speed restrictions listed on the “Chicago Subdivision” timetable page, located at the following Mile Post (MP) markers:

- MP 38.9 – MP 38.1: 35 mph
- MP 38.1 – MP 35.0: 50 mph
- MP 35.0 – MP 7.0: 70 mph

Temporary Speed Restrictions

- MP 37.5 – MP 37.0: 30 mph
- MP 24.5 – MP 24.0: 30 mph

Switch and Turnout Speeds

- MP 38.4 – MP 38.0: 35 mph
- MP 35.7 – MP 35.6: 35 mph
- MP 28.3 – MP 28.1: 35 mph
- MP 9.6 – MP 9.4: 35 mph

General Rule Compliance:

Horn Compliance

- MP 44.7 Shady Grove Lane (Horn sounded in advance)
- MP 42.8 Men & Equipment Rule 153
- MP 42.9 Kiley Avenue
- MP 41.9 Urban Expressway
- MP 41.5 Waterman Walkway
- MP 39.4 Robusto Road
- MP 35.2 Highway 4 Toll Road
- MP 35.1 Frontage Road
- MP 30.1 Service. Access Road
- MP 28.3 State Route 2
- MP 22.6 Belmont Road
- MP 22.0 – 18 QUIET ZONE (No Horn Sounded at any Crossings)
- MP 17.5 Union Avenue (Horn sounded in advance)
- MP 17.3 Technology Drive
- MP 17.2 Happy Feet Pedestrian Crossing
- MP 16.9 Old Farm Lane
- MP 16.8 Hinsdale Drive
- MP 16.0 – 7.0 QUIET ZONE (No Horn Sounded at any Crossings)

Radio Compliance

- MP 44.8 Advance Warning Wayside Sign (Adv. Warn.) MOW Rule 153 (@ 42.8-Verbal Acknowledge
- MP 39.5 Adv. Warn. 30 mph TSRB @ 37.5- Verbal Acknowledge
- MP 29.1 Approach Signal, Verbal Acknowledge
- MP 27.2 Hot Box Dector (HBD) Verbal Acknowledge
- MP 26.5 Adv. Warn. 30 mph TSRB @ 24.5-Verbal Acknowledge
- MP 10.48 Dragging Equipment Detector Verbal Acknowledge
- MP 10.24 Approach Signal, Verbal Acknowledge
- MP 8.8 Approach Signal, Verbal Acknowledge

3.2.8 Low Task Load (Scenario 2)

The Low Task Load condition of Scenario 2 consisted of the common baseline 39.0 mile Chicago Line run, but with the following additional task elements:

General Rule Compliance:

Horn Compliance

- MP 16.8 Vehicle in Right-Of-Way (ROW)
- MP 11.5 Trespasser in ROW

Radio Compliance

- MP 33.6: Signal Malfunction Control Signal Dropped to Red
- MP 28.4 (Napierville) Copy Form D
- MP 22.6 Form D Rule 138 Belmont Road
- MP 16.8 Vehicle in Right-Of-Way (ROW)
- MP 11.5 Trespasser in ROW

Unusual Events

- MP 33.6: Signal Malfunction Control Signal Dropped to Red
- MP 16.8 Vehicle in foul Hinsdale Road
- MP 11.5 Trespasser on ROW

Numeric Working Memory Task

Engineers were asked to store 8 numbers verbally transmitted via radio by the experimenter in memory and reproduce them in order after a 5 second delay. This task was repeated 4 times, 3 times during the simulation while in motion, and one time while the train was stopped. The working memory task¹⁹ was presented at:

- MP 45
- MP 37
- MP 18
- MP 9

3.2.9 High Task Load (Scenario 3)

The High Task Load condition of Scenario 3 consisted of the same 39.0-mile run as the Low Task Load condition of Scenario 2, but with the following *additional* task elements:

Temporary speed restrictions in effect:

MP 43.5 – MP 43.4: 20 mph

MP 16.9 – MP 16.8: 20 mph

General Rule Compliance

Horn Compliance:

MP 26.0 Men & Equipment Rule 153

MP 18.3 Vehicle in ROW

MP 12.0 Trespasser in ROW

Radio Compliance:

MP 45.5 Adv. Warn 20 mph TSRB @ 43.5- Verbal Acknowledge

MP 28.0 Adv. Warn. MOW Rule 153 (@ 26.0-Verbal Acknowledge

¹⁹Memory task MPs were chosen strategically before speed restrictions or other conditions contributing to distraction.

MP 27.2 HBD (no announcement from detector)
MP 20.6 (Fairview) Copy Form D
MP 18.9 Adv. Warn 20 mph TSRB @ 16.9- Verbal Acknowledge
MP 18.3 Vehicle in ROW
MP 16.8 Form D Rule 138 Hinsdale Road
MP 14.6 (La Grange-Stone Ave) Copy Bridge Strike Order MP 13.44 (
MP 12.0 Trespasser in ROW
MP Signal Malfunction Control Signal Dropped to Red

Unusual Events

MP 27.2 HBD (no announcement from detector)
MP 18.3 Vehicle in ROW
MP 12.0 Trespasser in ROW
MP 11.5 Signal Malfunction Control Signal Dropped to Red

Higher Working Memory Load

Twelve numbers were presented in the High Task Load condition (Scenario 3), whereas 8 numbers were presented from delayed recall in the Low Task Load condition (Scenario 2), at the same milepost location.

3.3 Results and Analysis

We first evaluated whether the two operational scenarios we developed were associated with progressively increased participant workload, as assessed by a subjective measure, and by a measure of secondary-task performance on the working memory task. We also investigated whether subjective and objective measures of mental workload differed between the control and SAT groups. We then examined the effects of task load on other measures of engineer attention and performance in both groups. All performance measures were subjected to analyses of variance (ANOVA) to examine the effects of task load.

3.3.1 Subject Mental Workload Ratings

The mean subjective mental workload ratings participants provided at the end of each scenario are shown in Figure 28. The mental workload scores were subjected to a two-way mixed ANOVA with group (control, SAT) as the between-subjects factor and task load as the within-subject factor (low load, high load.) This analysis yielded a significant main effect for task load $F(1,22) = 24.03, p < 0.01$. Workload scores were lower in the Low Task Load condition ($M = 6.00, SE = 0.33$) than in the High Task Load condition ($M = 7.88, SE = 0.19$). The main effect of group was not significant, $F(1,22) = 0.96$. However, inspection of the mean ratings in each condition revealed that there was a 10.5% reduction in subjective mental workload in the SAT group compared to the control group in the Low Task Load condition, with no difference in the High Task Load condition (see Figure 28).

3.3.2 Working Memory Performance

As in Study I, we also assessed mental workload using an objective measure, performance on a secondary working memory task, given that workload ratings provided by participants, while useful, can be subject to biases and individual differences in the way participants view the task. Two performance measures were computed from the numbers recalled by participants. The first,

free or non-ordered recall, was computed as the percentage of numbers (N) correctly recalled (without respect to order), or Memory performance = $N/(4*8)*100$ for the Baseline and Low Task Load conditions, where 8 numbers were presented 4 times. For the High Task Load condition where 12 letters were presented 4 times, Memory performance = $N/(4*12)*100$. The second working memory performance metric, ordered recall, was computed in the same way except that N was the number of numbers correctly recalled in the right order.

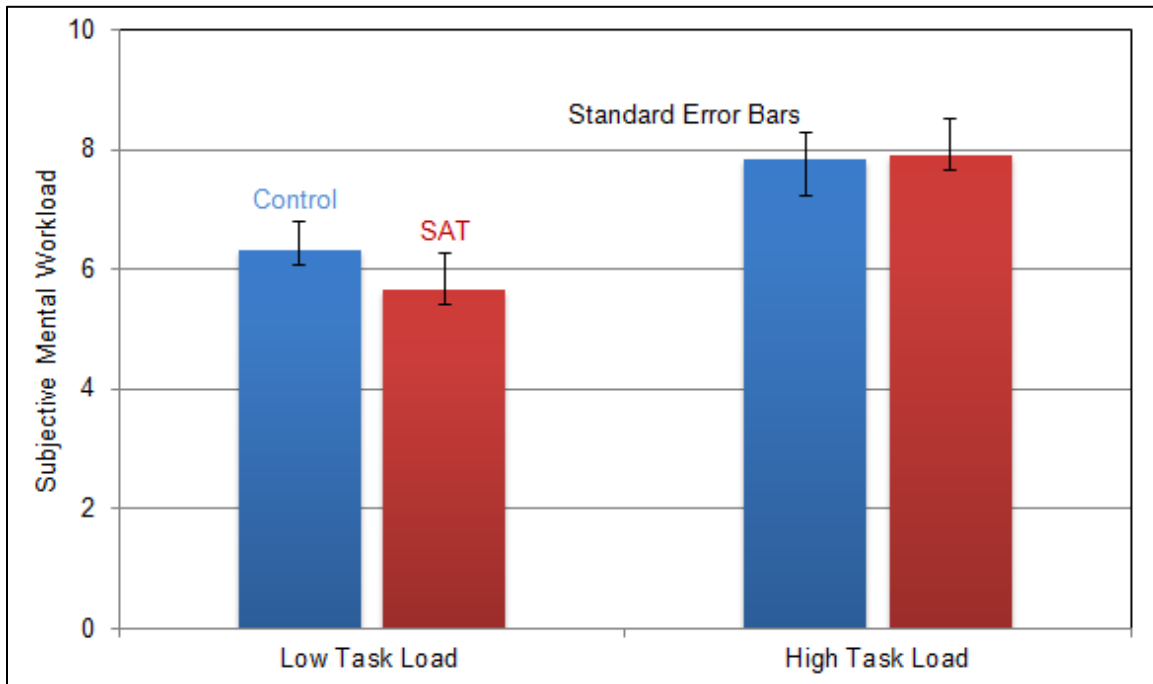


Figure 28. Mean Subjective Mental Workload Ratings Across Task Load Conditions and Groups

The mean percentages of working memory performance were subjected to a 2 x 2 x 2 mixed-groups ANOVA, with group (control, SAT) as the between-subject factor, and task load (low, high), and type of recall (free, ordered) as the within-subjects factors. This analysis yielded significant main effects for task load $F(1,22) = 64.63, p < 0.01$ and type of recall $F(1,22) = 190.79, p < 0.01$. Figures 29 and 30 show the mean working memory scores for free recall and ordered recall, respectively. Mean working memory performance scores were higher in the Low Task Load than in the High Task Load condition for both recall measures. Also, as expected, memory scores were higher for free recall ($M = 67.39, SE = 2.13$) than for ordered recall ($M = 40.13, SE = 3.05$). The main effect of group, $F(1,22) = 0.003$, and all two-way and three-way interactions were not statistically significant. However, inspection of the mean recall scores in each task condition revealed that the SAT group showed a 7.2% improvement in ordered recall in the Low Task Load condition (Figure 30).

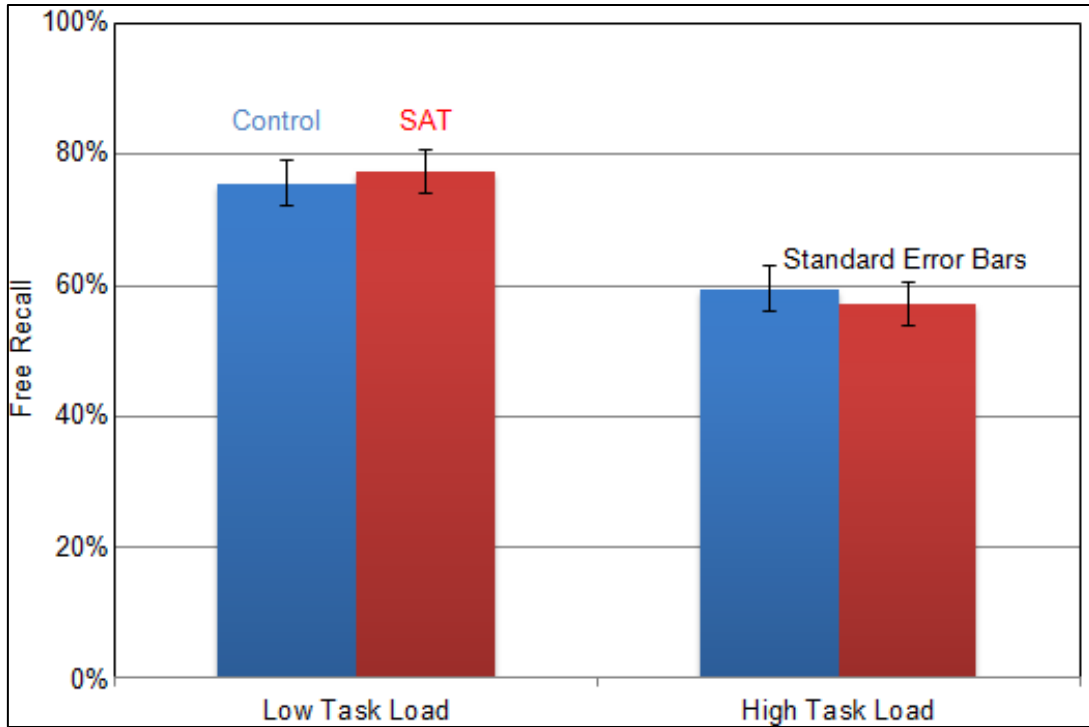


Figure 29. Mean Free Recall Percentages Across Task Load Conditions and Groups

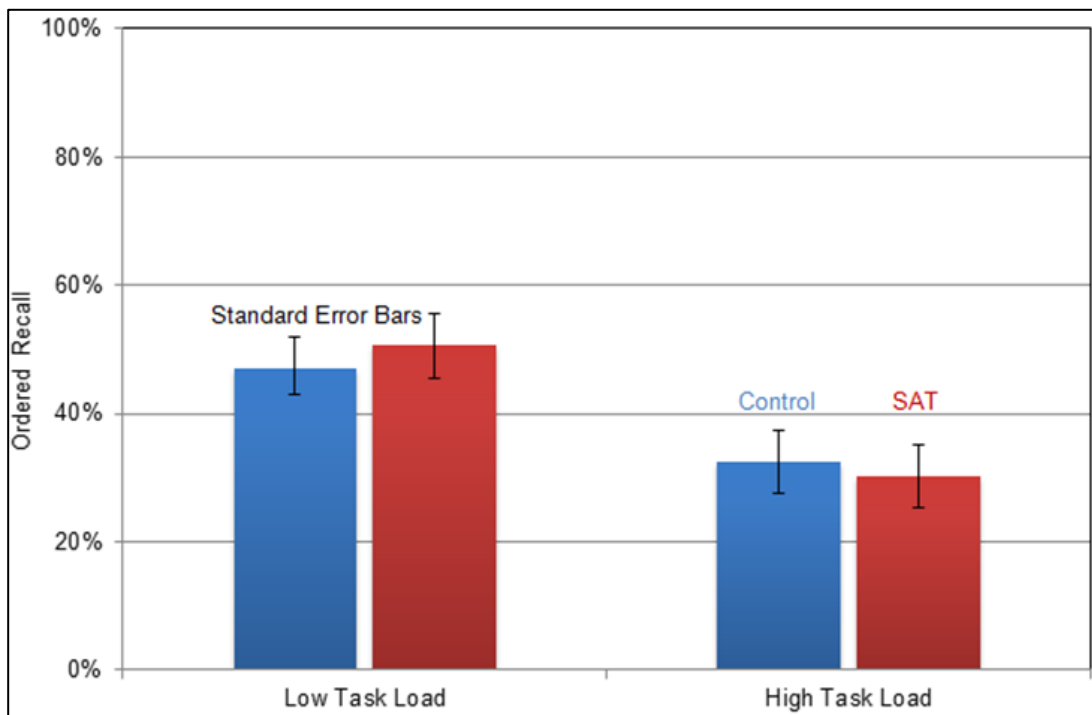


Figure 30. Mean Ordered Recall Percentages (With Standard Error Bars) Across Task Load Conditions and Groups

Having established that the two operational scenarios we developed were indeed associated with progressively increased task load, as assessed using both subjective and objective measures, we then examined the effects of task load and SAT on several measures of locomotive engineer attention and performance. These included speed restriction compliance, general rule requirements compliance, and reactions to unusual events.

3.3.3 Permanent Speed Restriction Compliance

Compliance with permanent speed restrictions was assessed in the same manner as in Study I. To summarize, if the maximum locomotive speed between the relevant MP markers did not exceed the posted maximum speed + 10% compliance was rated as 1; if the posted speed + 10% speed was exceeded, compliance was rated as 0. The mean permanent speed compliance scores across task load conditions and groups are shown in Figure 31.

The mean scores of permanent speed restriction compliance were subjected to a 2x2 mixed-groups ANOVA with group (control, SAT) as the between-subjects factor and task load as the within-subject factor (low load, high load). There was no significant main effect for task load $F(1,22) = .24$, group, $F(1,22) = .02$, or their interaction.

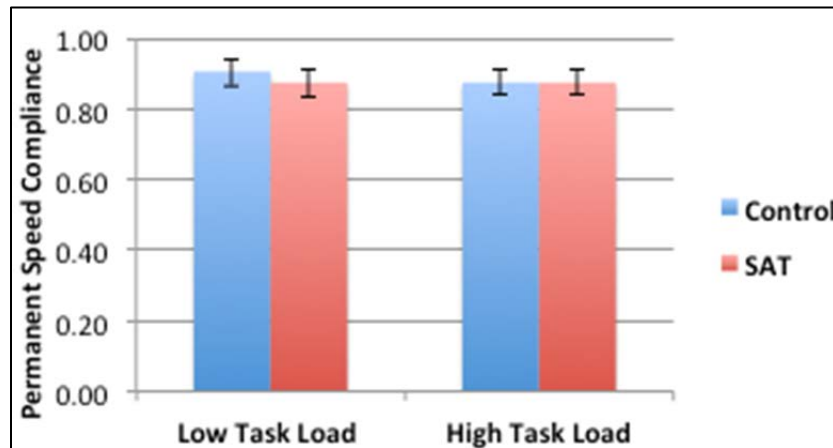


Figure 31. Permanent Speed Compliance Across Task Load Conditions and Groups

3.3.4 Temporary Speed Restriction Compliance

The mean scores of temporary speed restriction compliance are shown in Figure 32. These data were subjected to a two-way mixed ANOVA with group (control, SAT) as the between-subjects factor and task load as the within-subject factor (low load, high load). There was a significant main effect for task load $F(1,22) = 27.026$, $p < 0.01$. Mean temporary speed restriction scores were higher in the low task load condition ($M = 0.71$, $SE = 0.07$) than in the high task load condition ($M = 0.32$, $SE = 0.05$). However, there was no significant effect of group, $F(1,22) = 1.2$, nor an interaction between group and task load.

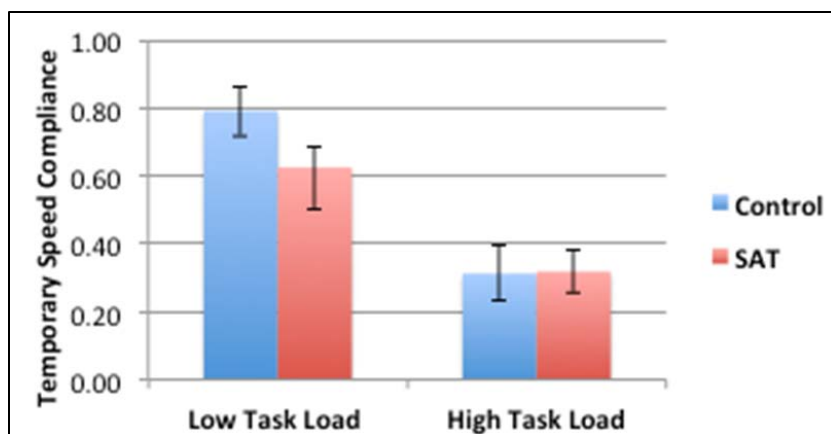


Figure 32. Mean Temporary Speed Compliance Across Task Load Conditions and Groups

3.3.5 General Rule Requirement Compliance

Horn Use. The location placement of the fifteen (15) separate highway grade crossings (HGX) was consistent in both low and high task scenarios. The applicable railroad rule requires the locomotive horn to be sounded in a signal-sequence of two longs, a short, and a long, for a minimum of 20 seconds in advance of and until the locomotive has actually occupied the applicable HGX.²⁰ The use of the locomotive horn was also evaluated at locations where maintenance-of-way (MOW) personnel were working,²¹ and at locations where unusual occurrences were presented such as trespassers or vehicles in the right-of-way. Additionally, there were two “Quiet Zones” designated by timetable mileposts, within which there were HGX where the locomotive horn was NOT to be sounded.²² Each test subject locomotive engineer was observed by the principal investigator who recorded either a 1 for compliance, or a 0 for non-compliance. The mean compliance scores were then averaged across events as seen in Figure 33. The mean horn compliance scores were subjected to a 2 x 2 mixed ANOVA with group (control, SAT) as the between-subject factor and task load (low, high) as the within-subjects factor. This analysis showed that there was not a significant main effect for task load $F(1,22) = 1.76$, although mean horn compliance scores were higher in the low task load condition ($M = 0.96$, $SE = 0.01$) than the high task load condition ($M = 0.93$, $SE = 0.02$). The main effect of group was not significant, $F(1,22) = 0.15$, nor was the interaction between group and task load.

²⁰49 CFR Part 222.21(b)(2).

²¹49 CFR Part 214.339.

²²Per 49 CFR Part 222.33.

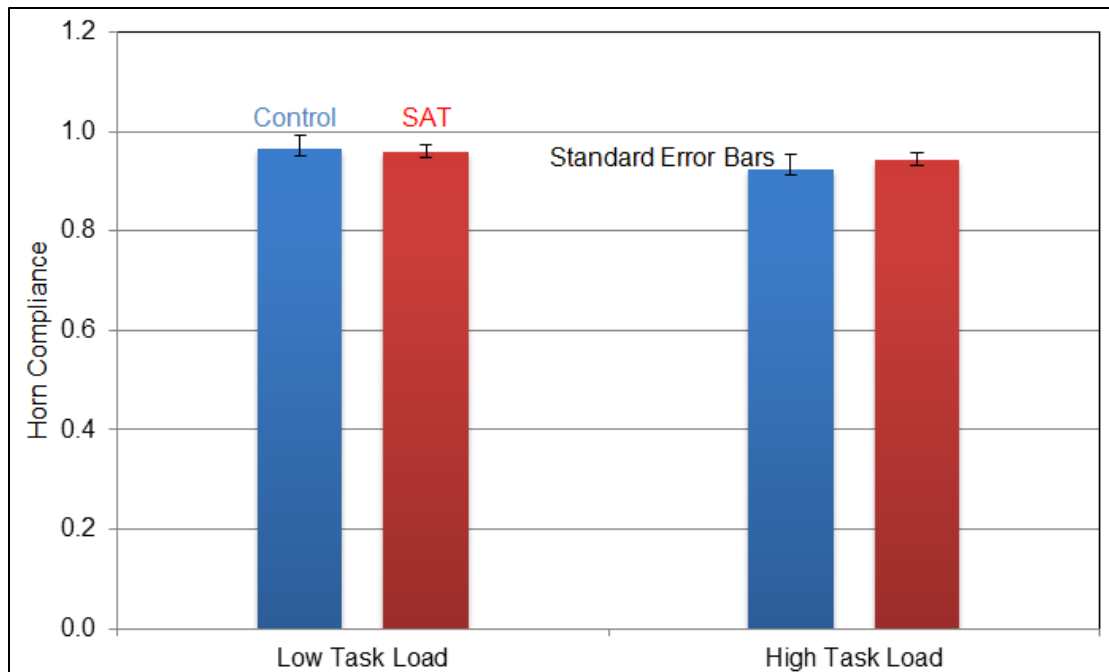


Figure 33. Horn Usage Compliance Across Task Load Conditions and Groups

Radio Communication Procedures. Railroad operating rules require the use of radio communication under certain circumstances, and that those communications be transmitted according to specified rule protocols. The location placement of three wayside signals displaying restrictive “approach” (yellow) indications was consistent in all three scenarios. The applicable railroad rule requires the operator to verbally communicate the name and location of the restrictive signal indication to a qualified employee on the engine or train as soon as it is visible.²³ Other restrictive signals placed only in scenarios 2 and 3 included:

- Restrictive wayside control signals (yellow aspect, approach indication; red aspect, stop indication).
- Restrictive wayside signage (Y/R [2 miles] prior to a MOW Protect order, Red and Yellow boards).
- Acknowledgment of a wayside defect detector that issues a radio status message.

Other events that required radio communication from the operating crew include notification to the train dispatcher of unusual events such as trespassers on the ROW, vehicles in the foul of the track, signal malfunctions, or transmission failures from wayside defect detectors. The principal investigator observed each locomotive engineer during each instance during the scenario where a radio communication response was required and recorded either a 1 for compliance, or a 0 for non-compliance. The mean compliance scores were averaged across all the radio communication required during the scenario. This was followed by the mean compliance scores being averaged

²³NORAC Rule 94(b)(1). In the scenarios presented to the test participants, they were advised to maintain radio communication with the scenario-based personalities of “qualified on-board crew member,” “train dispatcher,” and various MOW personnel, whose roles were provided by the principal investigator via simulated radio communication.

across events as seen in Figure 34. The mean radio usage compliance scores were subjected to a 2 x 2 mixed ANOVA with group (control, SAT) as the between-subject factor and task load (low, high) as the within-subjects factor. This analysis yielded a significant main effect for task load $F(1,22) = 9.81, p < 0.01$. Mean radio compliance scores were higher in the low task load condition ($M = 0.72, SE = 0.02$) than in the high task load condition ($M = 0.63, SE = 0.02$), see Figure 35. The main effect of group, $F(1,22) = 1.21$, and the interaction between group and task load were not significant.

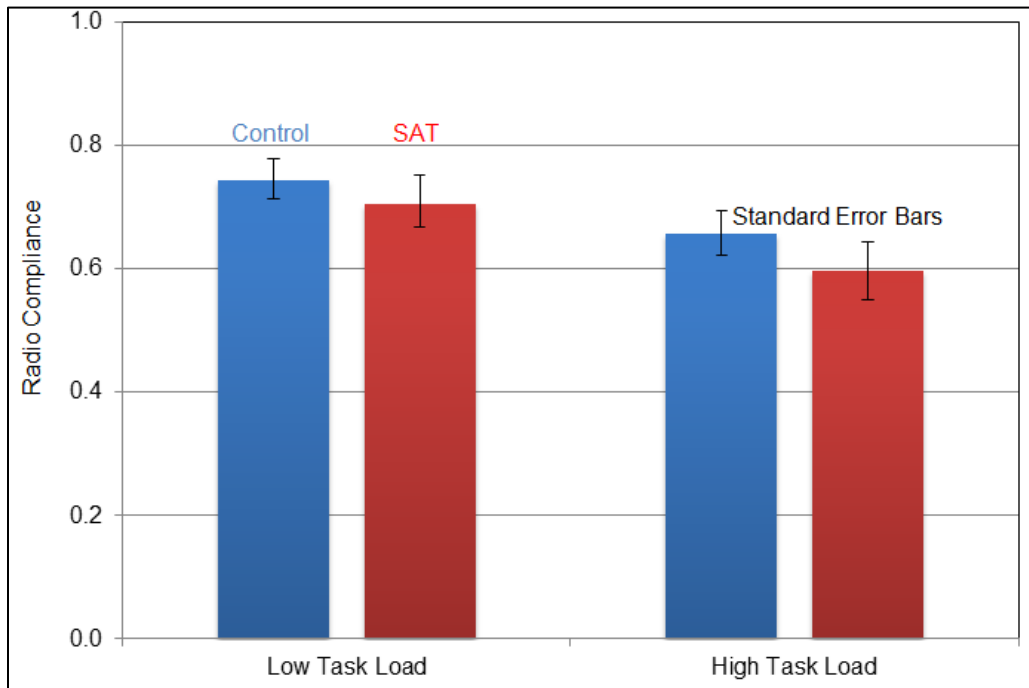


Figure 34. Radio Usage Compliance Across Task Load Conditions and Groups

Unusual Events Compliance. Unusual events for the purpose of this experiment were defined as unexpected high-consequence emergencies that carry the potential of loss of life or serious property damage. There were three in the low task load condition and four in the high task load condition, consisting of:

- A wayside signal displaying a PROCEED (green) indication that drops to RED (stop) on approach;
- A vehicle in the foul on the ROW;
- A trespasser in the foul on the ROW
- Failure of the wayside detector to announce (3 only)

In the case of the signal drop, the test subject compliance consisted of observing and reacting to the signal displayed by safely bringing the train to a stop (mandatory), and reporting the event to the train dispatcher. In the case of the vehicle and trespasser in the ROW, the test subject compliance consisted of observing and reacting to the event by slowing or stopping train movement (mandatory) and reporting the event to the train dispatcher by radio. The principal investigator observed each locomotive engineer during each instance during the scenario where a

radio communication response was required and recorded either a 1 for compliance, or a 0 for non-compliance. The mean compliance scores were then averaged across events (Figure 35).

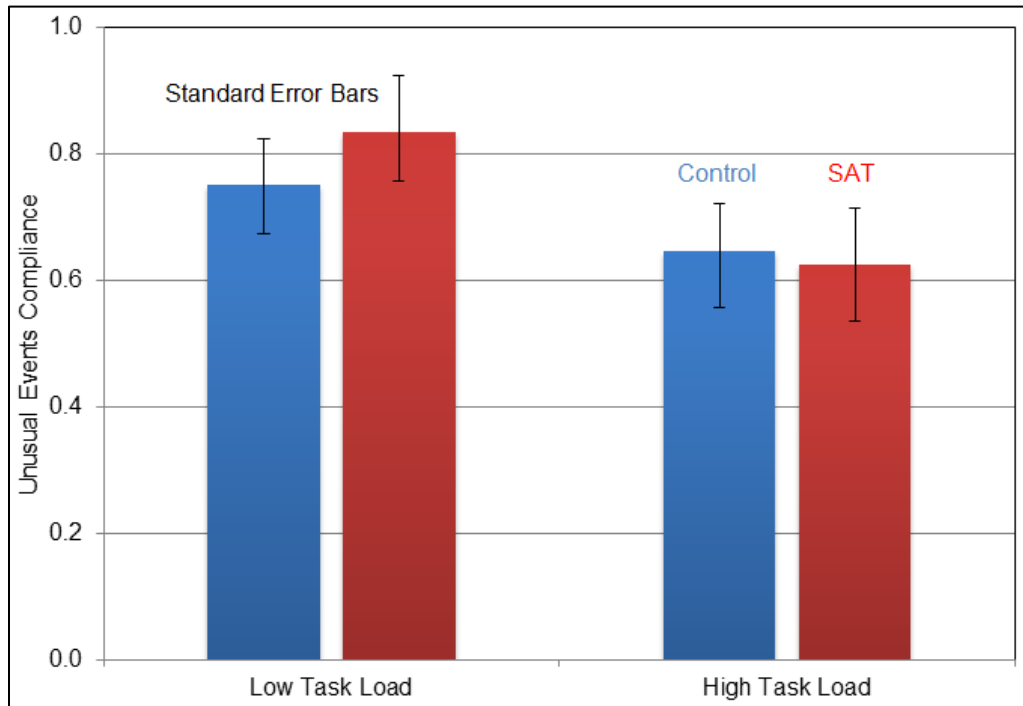


Figure 35. Unusual Events Compliance Across Task Load Conditions and Groups

The mean unusual events compliance scores were subjected to a 2 x 2 mixed ANOVA with group (control, SAT) as the between-subject factor and task load (low, high) as the within-subjects factor. This analysis yielded a significant main effect for task load $F(1,22) = 4.70, p < 0.05$. The mean compliance scores were higher in the low task load condition ($M = 0.79, SE = 0.06$) than in the high task load condition ($M = 0.64, SE = 0.06$). The main effect of group was not significant, $F(1,22) = 0.11$, and the interaction between group and task load were not significant. However, inspection of the unusual events compliance scores in each task load condition showed that compared to the control group, the group receiving SAT showed a 11.1% improvement in compliance in the low task condition.

3.4 Discussion

The results of Study II confirmed the findings from Study I that the operational scenarios developed to vary operational task load were successful in inducing graded levels of difficulty that impacted different aspects of locomotive engineer performance. Whereas Study I used three levels of task load across baseline, low task load, and high load, scenarios, Study II used only scenarios consisting of low and high levels of task load. In addition, because of hardware and software failure issues with the CTIL system at the time Study I was executed, Study II was completed with a newly-developed CTIL system that had similar but also different capabilities than the original systems, and with some differences in the out-of-window scenery. Despite these differences, the results of Study II showed that both objective and subjective measures of locomotive engineer mental workload provided validation that the two simulated scenarios we developed were indeed graded in task load and operational difficulty. The participants unanimously rated the high task load scenario as leading to significantly greater subjective

mental workload than the low task load scenario. Furthermore, objective indexes of mental workload, using free and ordered recall measures of a secondary working memory task [21], verified that there was a significant and marked reduction in working memory performance in the high task load condition compared to the low task condition.

As in Study I, we examined a number of aspects of procedural compliance, including horn usage, radio communication procedures, and reactions to unusual events. Horn usage compliance was high, but not perfect, averaging 95% in the low task load condition and 92% in the high load condition. Compliance with required radio communication procedures was significantly lower in the high task load condition (63%) than in the low task load condition (72%), indicating that this measure was sensitive to increased scenario difficulty. However, that both compliance rates were significantly less than 100% suggest that further examination, regarding the application of required testing,²⁴ monitoring and enforcement of rules and procedures relative to radio procedures included within the railroads program of instruction on operating rules pursuant to regulatory requirements²⁵ is recommended.

Compliance with required procedures given unusual events was also sensitive to task load, being significantly lower in the high task load condition (64%) than in the low task condition (79%). The research team noticed a variety of behaviors and reactions of test participants exposed to unusual events where a response would be expected. Unusual events included: a wayside signal displaying a green aspect (PROCEED indication) which dropped to a restrictive red aspect (STOP indication) on approach; highway vehicles unexpectedly in the foul of the railroad right-of-way; trespassers in the foul of track; and the failure of an identified way-side mechanical detection device to provide a broadcast radio announcement of mechanical integrity status. In some instances, participants failed to react with any expected rule-compliant response. Some were observed to be in a “head-down” posture, suggesting an inability to recognize certain visual cues presented on the scenario out-of-window view, while others exhibited behavior suggestive of inattentive blindness, ignorance and/or indifference to the required response. In other instances, participants either reacted with the expected rule-compliant response (e.g., sounding horn, application of brake, train dispatcher notification, etc.), or a partially rule-compliant response (a combination of some, but not all required responses).

There were no statistically significant effects of SAT on measures of operator performance or rule compliance, although there were some interesting suggestive trends that we discuss further below. The lack of a significant effect of SAT on locomotive engineer performance is disappointing, but not entirely unexpected. Because of the limited resources available for experimentation, the sample size was restricted to 12 participants per group, which is relatively small for a between-groups design for a study on training. This probably resulted in the study being underpowered to detect small to medium size effects of the experimental manipulation. Furthermore, the amount of training used in the current study—about 3 hours—was very short, and was probably insufficient to induce changes in performance. Previous studies of attentional training have typically found that performance is improved only after many tens of hours or days of training [22].

²⁴49 CFR Part 217.9.

²⁵49 CFR Part 217.11.

Despite these resource and statistical limitations, there were three trends in the results that were all associated with a single task condition and which are suggestive that SAT may be effective in mitigating distraction-related errors in rail operations. That condition was the scenario designed to impose only a low task load on the operator. In this condition, *but not the high task load condition*, there were trends indicative of the effectiveness of SAT for three measures: subjective mental workload, objective mental workload (working memory ordered recall), and compliance with procedures for dealing with unusual events. In particular, there was a 10.5% reduction in subjective ratings of mental workload in the group receiving SAT, compared to the control group. Consistent with this finding, ordered recall performance on the secondary working memory task, which is a more stringent objective measure of workload than free recall, was 7.2% higher in the SAT group than in the control group, again pointing to a beneficial effect of SAT on mental workload. Finally, compliance with procedures for dealing with unusual events was 11.1% higher in the SAT group than in the control group. These gains due to SAT are summarized in Table 3. It is noteworthy that while the gains for operator workload are important, more important is the *bottom line*—enhanced compliance to unusual events—because it is precisely such events that are typically associated with incidents and accidents.

Table 3. Amount of Improvement in Locomotive Engineer Performance with SAT in the Low Task Load Condition

Metric	Amount of Improvement due to SAT
Subjective Mental Workload	10.5%
Objective Mental Workload	7.2%
Compliance with procedures for dealing with unusual events	11.1%

While these performance changes associated with SAT are suggestive and not statistically significant, they are nevertheless interesting and intriguing because they were found consistently in the low task condition but not in the high task load condition. As outlined in the educational component of the training protocol, distraction-related errors can occur at both low and high task load, but for different underlying reasons. At high task load, errors may occur due to limitations in attentional resources [23]. At low task load, however, errors may reflect periodic lapses in attention associated with mind wandering or mental rumination [24].

That SAT led to performance improvements in the range of 7.2% – 11.1% in the low task condition is encouraging with respect to the potential utility of this type of attentional training. Additional research with a larger sample size and longer training periods is needed to confirm these trends. Future research could also use probes to track mind wandering and mental rumination, as well use questionnaires to assess mindfulness, so that more reliable links between these mental states and distraction-related errors can be established.

4. Conclusion

This project investigated the role that various elements of cognitive distraction play in major rule violations by locomotive engineers in railroad operations and the potential mitigation of distraction-related errors with sustained attention training (SAT).

Study I examined the effects of task load over three scenarios on performance and attentional errors in 12 experienced locomotive engineers. The results consistently supported the conclusion that as the level of task-related distraction increased across scenarios, different measures of operator performance decreased proportionately. It also appears that some of the performance measures analyzed, such as permanent speed restriction and radio procedure compliance did not produce statistically significant changes with variations in task load. However, the remaining measurements of (1) subjective mental workload, (2), objective mental workload as measured by secondary-task working memory performance, (3) horn use compliance, and (4) response to unusual events consistently supported the validation of the Study I experimental protocol rationale, as well as providing the underlying foundation for supporting the recommendation of necessary modifications to the experiment model to be used in Study II.

Study II examined the potential of SAT to mitigate distraction-related errors in locomotive engineer performance, mental workload, and attentional errors during simulated commercial rail operations. The results confirmed the findings from Study I that the operational scenarios developed to vary operational task load were successful in inducing graded levels of difficulty that impacted different aspects of locomotive engineer performance. Both objective and subjective measures of locomotive engineer mental workload provided validation that the two scenarios were graded in task load and operational difficulty. However, there were no statistically significant effects of SAT on attentional errors, mental workload, or performance. Nevertheless, the potential effectiveness of SAT in the *low task* load condition was observed suggesting its documented effectiveness within three measures: subjective mental workload, objective mental workload (working memory ordered recall), and compliance with procedures for dealing with unusual events. That these effects of SAT, albeit not statistically significant, were found consistently in the low task load condition suggests that errors under low task load may reflect periodic lapses in attention associated with mind wandering or mental rumination. Future studies of distraction mitigation would be warranted with a larger sample of locomotive engineers and longer duration SAT.

Abbreviations and Acronyms

ANOVA	Analysis of Variance
ABS	Automatic Block Signal System
BLE	Brotherhood of Locomotive Engineers
CFR	Code of Federal Regulations
CRM	Crew Resource Management
CTIL	Cab Technology Integration Laboratory
DOT	United States Department of Transportation
FMVSS	Federal Motor Vehicle Safety Standards
<i>F</i>	F Statistic
FRA	Federal Railroad Administration
HGX	Highway-Rail Grade Crossing
HMI	Human-Machine Interface
M	Mean
MBTA	Massachusetts Bay Transit Authority
MCBR	Massachusetts Bay Commuter Railroad
M-Fit	Mind Fitness Training
MOW	MOW
MP	Mile Post location on a railroad territory
OSHA	Occupational Safety and Health Administration
<i>p</i>	Probability
PS	Passenger Station
ROW	Right of Way
SAT	Sustained Attention Training
SD-40	a 6-axle locomotive built by General Motors Electro-Motive Division
<i>SE</i>	Standard Error
TCS	Train Control System
TSRB	Temporary Speed Restriction Bulletin
UTU	United Transportation Union
XOVER	Rail Cross-Over Track

Endnotes

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