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Auditory Attention and Comprehension during a Simulated Night Shift:

Effects of Task Characteristics

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Abstract

Objective: The current study investigated performance on a dual auditory task during a simulated night shift.

Background: Night shifts and sleep deprivation negatively affect performance on vigilance-based tasks but less is known about the effects on complex tasks. Because language processing is necessary for successful work performance, it is important to understand how it is affected by night work and sleep deprivation.

Method: Sixty-two participants completed a simulated night shift resulting in 28 hours of total sleep deprivation. Performance on a vigilance task and a dual auditory language task was examined across four testing sessions.

Results: The results indicate that working at night negatively impacts vigilance, auditory attention, and comprehension. The effects on the auditory task varied based on the content of the auditory material. When the material was interesting and easy, the participants performed better. Night work had a greater negative effect when the auditory material was less interesting and more difficult.

Conclusion: These findings support research that vigilance decreases during the night. The results suggest that auditory comprehension suffers when individuals are required to work at night. Maintaining attention and controlling effort especially on passages that are less interesting or more difficult could improve performance during night shifts.

Application: The results from the current study apply to many work environments where decision making is necessary in response to complex auditory information. Better predicting the effects of night work on language processing is important for developing improved means of coping with shiftwork.

Keywords: sleep, work/rest cycles, circadian rhythms; human performance modeling; dual task; information processing; attentional processes

Précis: Auditory dual processing was negatively impacted during a simulated night shift. More specifically, less interesting and more difficult auditory material resulted in poorer performance. Better understanding the impact of night work on complex language processing will help provide more effective coping strategies for working at night.

INTRODUCTION

Shiftwork and sleep deprivation are increasingly common in today's 24-hour-a-day global economy and operations. Human endogenous circadian rhythms interact with shiftwork resulting in sleep deprivation which negatively affects performance (Reinberg & Ashkenazi, 2008) and health (Arendt, 2010). Until recently, research on performance under sleep deprivation conditions often focused on vigilance tasks, in part because vigilance is particularly sensitive to the effects of sleep deprivation. Most work settings, however, involve more complex tasks, such as language comprehension. Although language skills and comprehension are critical elements of many jobs, little research has focused on language abilities when working at night under sleep deprivation conditions. Furthermore, few studies have adequately captured the complexity of many language tasks and the potential for characteristics of the task content to impact performance in night shift workers.

Previous studies report that vigilance and attention suffer due to sleep loss (e.g., Kendall, Kautz, Russo, & Killgore, 2006; Lim & Dinges, 2010; Roca, et al., 2012) and that sleep disruption negatively affects performance on simple cognitive tasks more than complex cognitive tasks (Wickens, Hutchins, Laux, & Sebok, 2015). In contrast, Pilcher, McClelland and colleagues (2007) found that performance during a simulated night shift under sleep deprivation conditions is decremented on complex language tasks but not more basic language processes. Similarly, previous research has found expressive speech, speech production, and receiving complex instructions to be more difficult under sleep deprivation conditions (Harrison & Horne, 1997; Kim, et al., 2001; Schein, 1957).

One outcome of working at night and sleep deprivation could be a decreased capacity to successfully manage dual-task processing. Jackson and colleagues (2011) found that sleep-

deprived individuals had significantly poorer performance on a divided attention task involving simultaneous auditory and visual attention. A study where participants completed subtraction problems while driving also found impaired performance under moderate sleep loss (Rupp, Arnedt, Acebo, & Carskadon, 2004) while Sauer and colleagues (2003) found no change in primary task performance but a decrease in performance on a secondary task under simulated night work conditions. It is important to note, however, that not all dual tasks seem to result in detriments in performance in sleep-deprived persons. Requiring performance on a dual task using a visuomotor tracking task with visual detection as a secondary task helped to temporarily improve performance on the main task under sleep deprivation (Gazes, et al., 2012). Likewise, when working with partners, performance on a dual task combining tracking with cognitive tasks resulted in improved performance in a simulated night shift (Pilcher, Band, Odle-Dusseau, & Muth, 2007).

Research suggests that other task characteristics may also affect performance when working at night. Tasks that are seen as motivating or that encourage effort (Odle-Dusseau, Bradley, & Pilcher, 2010) or tasks that encourage attention or are intrinsically interesting (Pilcher, Band, et al., 2007; Tremaine, et al., 2010) could enhance or help maintain performance during the night shift. The effects of task characteristics on language processing tasks, however, are not yet clear. Because language processing and comprehension are common in the workplace, the characteristics of the task could be an important consideration in understanding how shiftwork and sleep deprivation could affect performance in the workplace.

The main purpose of the current study was to examine the effects of a simulated night shift on an auditory task requiring dual processing. We hypothesized that auditory comprehension and attention would decrease across the simulated night shift. Based on the

primary findings from the study, we completed additional exploratory analyses on the effects of the level of interest and difficulty of the specific auditory passages on performance across the simulated night shift. For these additional analyses, we hypothesized that the effects on performance would differ based on the interest and difficulty level of the auditory passage. We expected that performance on audio passages that were more interesting and less difficult would be less affected than performance on less interesting and more difficult passages.

METHOD

The primary study, Study 1, was designed to assess the effects of sleep deprivation on performance on a complex auditory language task. Initial analyses of the data obtained in Study 1 revealed that there were performance differences based on which audio book was presented during the testing sessions. Specifically, repeated-measures ANOVAs revealed significant differences in performance based on the book presented, when collapsing across testing sessions. There was a difference in main point performance ($F(3,183) = 4.06$, $p < .008$, $\eta p^2 = .06$) and a difference in key word hit percentage ($F(3,183) = 25.90$, $p < .001$, $\eta p^2 = .30$). These findings prompted Study 2, which sought to determine if there were intrinsic differences between the four audio books. Therefore, additional participants in Study 2 determined the level of interest and difficulty of the four audio passages. The results of Study 2 were then applied to better understand the data obtained in Study 1.

Study 1

Participants

Sixty-two students (42 males, 20 females; age: 22.8± 2.7) participated in the simulated night shift study. This research complied with the American Psychological Association Code of

ethics and was approved by institutional review board at Clemson University. All participants signed informed consent forms before participating in the study.

Procedures

Volunteers for the sleep deprivation study were recruited through flyers posted on campus offering $150 for participation in a sleep deprivation study. Interested volunteers completed a screening questionnaire. Participation criteria were to be in good health, sleep at night, have no documented sleep disorders, not use tobacco or drugs, and not drink excessive alcohol. Individuals who met the criteria were divided into groups of four for testing. The selected participants came to the lab three days in advance of the study to learn about the study and sign informed consent forms. Participants were instructed to sleep 8 hours a night for the remaining nights before the study, not to consume alcohol the day before the study, and not to consume caffeine or excess sugar the morning of the study.

At the meeting, participants were given actigraphs (Actiwatch; Mini Mitter Company Inc., Bend, OR.) and daily sleep logs to record their sleep/wake activity for the three days prior to the study. The Actiwatch is a wristwatch-like device that measures wrist movement as an objective measure of sleep/wake activity. Participants were asked to wear the Actiwatches at all times over the three days unless showering or swimming. The sleep logs were used to record information about what time the participant went to sleep, what time they woke up, nap time, and sleep quality.

The study took place across 2 days. Research assistants called the participants on Day 1 at a designated time between 8:30 and 9:00 am. Participants reported to the campus lab at 9:30 am, were driven to an off-campus research facility and were then continuously monitored to

ensure they remained awake for the duration of the study. In total, the participants remained awake for approximately 28 hours. They completed two training sessions prior to the onset of the first testing session (Table 1). The participants had lunch and dinner provided as well as several break times. During breaks, participants could snack, socialize, play board games, or watch selected DVDs to ensure they stayed awake but were not overly active. Food such as salads, sandwiches, pizza, and fresh fruit, and beverages was provided for the participants throughout the study. No caffeine or excess sugar was permitted. The study ended at 1:30 pm on Day 2 when the participants were driven to their place of residence.

Table 1. Study Design

Day 1	
10:00 AM – 10:30 AM	Arrival at off-campus lab
10:30 AM – 11:30 AM	Training Session I
11:30 AM – 2:15 PM	Lunch break
2:15 PM – 4:15 PM	Training Session II
4:15 PM – 4:45 PM	Break
4:45 PM – 5:30 PM	Subjective measures (e.g., global sleep quality, mood)
5:30 PM – 6:30 PM	Dinner break
6:30 PM – 10:30 PM	Test Session I
10:30 PM – 11:00 PM	Break
11:00 PM – 12:00 AM	Testing Session II
Day 2	
12:00 AM – 3:00 AM	Testing Session II continued

3:00 AM – 3:30 AM	Break
3:30 AM – 7:30 AM	Testing Session III
7:30 AM – 8:00 AM	Break
8:00 AM – 12:00 PM	Testing Session IV
12:00 PM – 12:30 PM	Lunch
12:30 PM – 1:30 PM	Other activities
1:30 PM	Transport to residence

Participants completed four testing sessions from 6:30-10:30 pm, 11:00 pm-3:00 am, 3:30-7:30 am, and 8:00 am-12:00 pm to simulate a night shift. The testing sessions included several complex cognitive tasks (e.g., verbal and quantitative portion of the GRE, decision making task) and working memory tasks (e.g., category recall task, order recall task, Sternberg memory task). In addition, vigilance was monitored using the Psychomotor Vigilance Task and auditory performance was assessed using a dual auditory task. The Psychomotor Vigilance Task and the dual audio task are reported in the current study. The order of the tasks was counterbalanced over the four testing sessions and across participants to control for any order effects. Because the dual audio task contained passages from four books (see below) each of the books was presented once in a testing session with the order of book presentation counterbalanced across the testing sessions.

Measures

The Psychomotor Vigilance Task (PVT; Ambulatory Monitoring, Inc., Ardsley, NY) is commonly used in sleep deprivation research (Dinges & Powell, 1985). The PVT is a 10-minute

vigilance task with inter-stimulus intervals ranging between 2 and 10 seconds. The PVT provides measures of reaction time and number of lapses (reaction time greater than 500 ms). Participants completed a 2-minute version of the PVT for training.

The dual audio task measured auditory attention through identification of keywords, language comprehension through identifying main points, and auditory dual-task performance by completing both components of the task simultaneously. To train for the dual audio task, the task was first described to the participants. They then listened to a 3-minute passage while viewing the computer screen for the task. The participants practiced using the keyword button and typing notes in a note box. At the conclusion of the training passage, three text boxes appeared below the note box allowing the participants to see where they would type the three main points from the audio passage. Training for the dual audio task took about five minutes.

During the testing sessions, participants listened to portions of four audio books. The task took approximately 30 minutes to complete in each testing session. The order of presentation of the four audio books was counterbalanced across the testing sessions. The non-fiction books were: The 7 Habits of Highly Effective People by Stephen R. Covey, DNA: The Secret of Life by James D. Watson, The Americanization of Benjamin Franklin by Gordon S. Wood, and How the Irish Saved Civilization by Thomas Cahill. The passages were 24 to 28 minutes of the first chapter or introduction of each book.

At the start of each audio passage, the researcher informed the participant of the keyword for that passage and reminded the participant to click on the keyword box whenever they heard the word. The keyword for each passage was chosen in advance to ensure it was present 8 to 10 times and was distributed fairly evenly. The keyword for 7 Habits, “paradigm(s)”, occurred 10 times, the keyword for DNA, “characteristic(s)” occurred 8 times, the keyword for Benjamin

Franklin, “character(s)”, occurred 10 times, and the keyword for Irish Saved Civilization, “Rhine”, occurred 9 times. Participants were instructed to stop taking notes when they heard the keyword, click on the keyword box, and then resume note taking. The maximum time for a keyword response was five seconds from the end of the keyword. If the participant clicked the keyword box within five seconds, it was counted as a hit. A false alarm occurred if the participant clicked the keyword box when no keyword was presented or after the five-second interval. At the end of the passage, the three main points boxes appeared on the computer screen below the note box. Participants were given three minutes to summarize the three main points using their notes.

The three main points entered by each participant were scored by comparing them to a list of possible main points. The possible main points were determined from six independent reviewers who found 6 to 10 possible main points for each passage. Two independent scorers reviewed the participants’ responses to determine how well they matched the possible main points and assigned numeric points based on their review with a possible total of 3 points. Each participant was given 1 point for a correct summary of a main point, 0.5 points for a partially correct main point, and 0 points if the participant did not provide a correct main point. The raters agreed on the main points score on 89% of the data points. When the two scorers did not agree, they conferred and reached a common score.

Study 2

Participants

An independent sample of eighteen students (2 males, 16 females; 20.2 yrs ± 1.0) completed ratings on the level of interest and difficulty of the audio books used in the dual audio task. These participants agreed to informed consent by completing the audio book ratings.

Procedure

Participants listened to the first 10 minutes of each audio passage. The order of presentation of the audio books was counterbalanced across participants. After listening to each passage, participants completed a survey rating the passage on how interesting it was (0: not at all to 100: extremely interesting) and how difficult it was to understand (0: very easy to 100: extremely difficult) on a 100 mm visual analogue scale (VAS). After listening to the audio passages, participants filled out an additional survey to rank the four books on how interesting they were (1: most to 4: least interesting) and how easy or difficult to understand they were (1: easiest to 4: most difficult). The participants completed their ratings in approximately 45 minutes.

Data Analysis

SPSS version 21 was used for all data analyses. Primary analyses were first conducted using data obtained in Study 1. Performance on the PVT was examined as evidence of vigilance across the testing sessions. Two repeated-measures ANOVAs were used to examine changes in reaction time and lapses. The inverse of reaction time was used to normalize the distributions.

Overall performance on the dual audio task was first examined by four repeated-measures ANOVAs to identify changes in main point scores, keyword hit percent, keyword false alarms, and sensitivity to the keyword task across the simulated night shift. Sensitivity was indexed by d-prime (d') a signal detection measure that assesses the participants' ability to correctly detect a signal (the keyword) from the remainder of the auditory content (Pastore & Scheirer, 1974; Stanislaw & Todorov, 1999). Sensitivity was calculated by subtracting the standardized false alarm rate from the standardized hit rate.

In Study 2, the VAS interest and difficulty ratings were compared using a MANOVA since the VAS ratings were significantly correlated for three of the four books. Subsequent ANOVAs and pairwise comparisons were used to determine three categories of books based on interest and difficulty levels.

Additional analyses were conducted to examine performance on the dual audio task in Study 1 based on the three book categories that were developed based on the results of Study 2. It is important to note that because the tasks were counterbalanced across the night and across participants, the participants listened to different audio books in different testing sessions; therefore, performance on one audio book could not be tracked across each testing session. Four one-way ANOVAs were conducted to determine the differences in performance among the book categories for each testing session on main point identification, keyword hit percent, keyword false alarms, and d'. Post-hoc tests were used to determine differences for each testing session.

RESULTS

Study 1

Sleep Data

Data from the sleep logs and actiwatches indicated that participants followed instructions and were well rested at the start of the experiment. The actiwatch data indicated that participants slept an average of 7 h 26 min (*SD* = 50.6 min) across the three nights prior to the study and an average of 7 h 13 min (*SD* = 53 min) the night before the study. The subjective sleep log data supported the results from the actiwatches. Participants reported sleeping an average of 6 h 48 min (*SD* = 40.2 min) over the three days prior to the study and 7 h 18 min (*SD* = 47.9 min) the night before the study.

283

284 **Psychomotor Vigilance Task**

285 Results of two repeated-measures ANOVAs revealed that performance on the PVT
286 decreased across the four testing sessions. Reaction time ($F(2.45, 154.10) = 71.58$, $p < .001$, $\eta_p^2 =$
287 .53) and lapses ($F(2.44, 153.99) = 19.40$, $p < .001$, $\eta_p^2 = .24$) significantly increased across the
288 testing sessions (Greenhouse-Geisser test values reported because assumption of sphericity was
289 violated). For both effects, a linear trend was significant (reaction time: $F(1,63) = 143.85$, $p <$
290 .001, $\eta_p^2 = .70$; lapses: $F(1,63) = 43.39$, $p < .001$, $\eta_p^2 = .41$), while cubic and quadratic trends
291 were not.

292 **Dual Audio Task**

293 There was a decrease in main point performance over time ($F(3,183) = 17.57$, $p < .001$,
294 $\eta_p^2 = .22$) on the dual audio task. Further examination showed that a linear trend explained the
295 most variance ($F(1,61) = 31.83$, $p < .001$, $\eta_p^2 = .34$), however, the cubic effect was also
296 significant ($F(1,61) = 14.37$, $p < .001$, $\eta_p^2 = .19$. The quadratic relationship was non-significant.
297 Second, there was a decrease in keyword hit percent over time ($F(3,183) = 15.82$, $p < .001$, $\eta_p^2 =$
298 .21). Further tests revealed this relationship was linear ($F(1,61) = 46.95$, $p < .001$, $\eta_p^2 = .44$) and
299 that the quadratic and cubic relationships were non-significant. Lastly, there was no significant
300 change in false alarm rates across sessions. However, there was a decrease in sensitivity, as
301 indicated by d', to the keyword task ($F(3,183) = 2.83$, $p = .04$, $\eta_p^2 = .04$). Again, there was a
302 linear trend ($F(1,61) = 8.14$, $p < .006$, $\eta_p^2 = .12$), while the quadratic and cubic trends were non-
303 significant. In sum, performance may somewhat rebound for main point performance (i.e., a
304 cubic effect), however, the effects were predominantly linear, such that performance on the dual
305 audio task decreases across the simulated night shift.

306 **Study 2**

307 Because there were differences in performance in Study 1 based on the book, the interest
308 and difficulty levels of the books were further considered in Study 2. The analyses of the task
309 characteristics of the audio books indicated that the overall ranking of the books based on
310 interest level was: 7 Habits as most interesting followed by DNA, Benjamin Franklin, and Irish
311 Saved Civilization. The overall ranking of the books based on difficulty level was: 7 Habits as
312 the easiest to understand followed by DNA, Benjamin Franklin, and Irish Saved Civilization
313 (Table 2).

Table 2. Descriptive statistics and pairwise comparisons of subjective content ratings of audio books

Book		VAS Interest	VAS Difficulty	Interest Rank (1=most interesting)	Difficulty Rank (1=easiest to understand)
7 Habits	*Mean*	63.22 [2,3,4]	24.44 [4]	1.61	1.78
	SD	22.69	22.10	0.78	1.11
DNA	*Mean*	45.11 [1,4]	33.11 [4]	2.33	2.22
	SD	22.68	21.34	0.97	1.00
Ben Franklin	*Mean*	36.94 [1,4]	32.61 [4]	2.44	2.44
	SD	21.21	19.62	0.92	0.71
Irish	*Mean*	21.17 [1,2,3]	51.83 [1,2,3]	3.61	3.56
	SD	20.50	26.94	0.84	0.86

[1] Significantly different from The 7 Habits of Highly Effective People, $p < .05$
[2] Significantly different from DNA: The Secret of Life, $p < .05$
[3] Significantly different from The Americanization of Benjamin Franklin, $p < .05$
[4] Significantly different from How the Irish Saved Civilization, $p < .05$

314

315 There was a significant difference among the four books when collapsing across both
316 VAS ratings ($F(6,12) = 5.79$, $p = .01$, $\eta_p^2 = .74$). There were also significant differences among

the books for the VAS interest rating ($F(3,51) = 13.37$, $p < .001$, $\eta_p^2 = .44$) and the VAS difficulty rating ($F(1.99, 33.75) = 5.63$, $p = .008$, $\eta_p^2 = .25$; Greenhouse-Geisser test values reported because assumption of sphericity was violated).

Pairwise comparisons found no significant differences between DNA and Benjamin Franklin on either VAS measure (Table 2). The average of performance for these books was used for additional analyses. The 7 Habits passage was significantly more interesting than the other books. Irish Saved Civilization was rated as significantly less interesting and more difficult than the other books. Books were categorized based on level of interest and level of difficulty (Table 3). For the remainder of this paper, the book categories will be referred to by their interest level (high, average, or low).

Table 3. Audio Book Categorization

Book(s)	Category Name	Interest Level	Difficulty Level
7 Habits of Highly Effective People	High Interest	High	Low
DNA: The Secret of Life *and* The Americanization of Benjamin Franklin	Average Interest	Average	Average
How the Irish Saved Civilization	Low Interest	Low	High

Exploratory Analyses of Dual Task Performance using Book Categorization

The book categorizations were used to further explore potential differences on auditory language performance during a simulated night shift (Study 1), based on the book that was presented to the participant in a given session. Thus, the categories identified in Study 2 were applied to the Study 1 data to compare individuals completing different books across the simulated night shift.

There were no differences in main point identification for the first three testing sessions when comparing the book categories. In testing session four, there was a significant difference ($F(2,59) = 3.79$, $p = .03$, $\eta_p^2 = .11$) with performance on the high interest category significantly better than on the low interest category ($p = .04$). Overall, the highest performance on main point identification was for the high interest category (Figure 1).

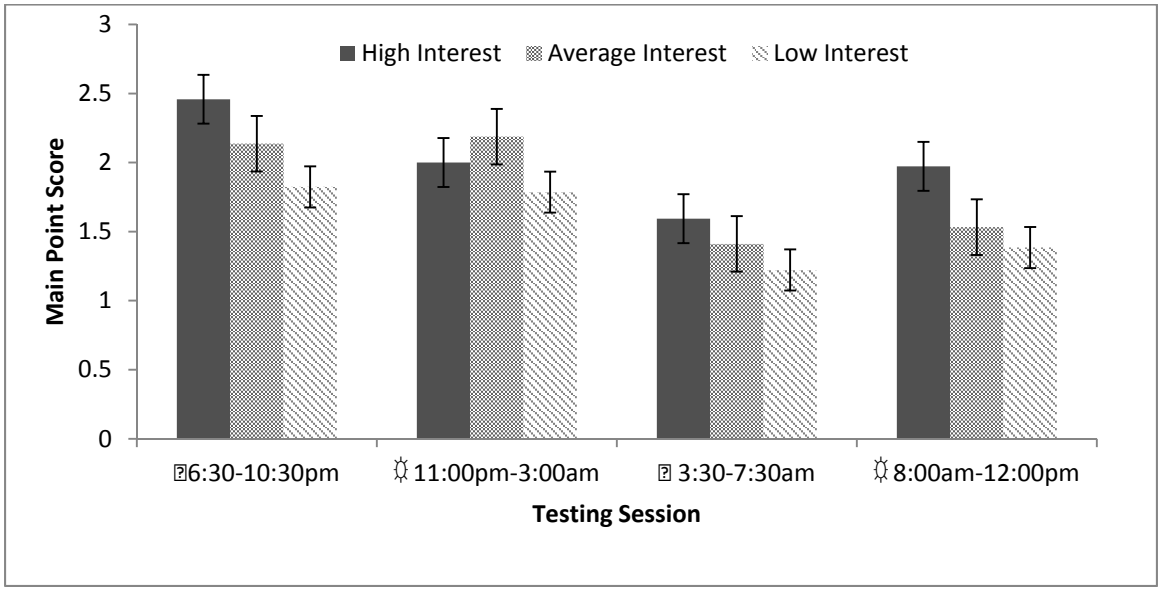

Figure 1. Performance in main point identification by testing sessions. Scores range from 0 to 3. Error bars represent standard errors of the mean. High Interest: 7 Habits of Highly Effective People; Average Interest (average of two books): DNA: The Secret of Life and The Americanization of Benjamin Franklin; Low Interest: How the Irish Saved Civilization.

There were significant differences in keyword performance for three of the four testing sessions when comparing the book categories. In session one, there was a significant difference among book categories on keyword hit percent ($F(2,59) = 13.12$, $p < .001$, $\eta_p^2 = .31$) with performance on the average interest category significantly lower than the high interest ($p = .04$) and low interest ($p < .001$) categories. In session three, there was a significant difference among book categories in keyword hit percent ($F(2,59) = 8.30$, $p = .001$, $\eta_p^2 = .22$) with performance on

the average interest category significantly lower than both the high interest (p = .02) and low interest (p = .001) categories. In session four, there was a significant difference among book categories in keyword hit percent ($F(2,59) = 6.33$, p = .003, η_p^2 = .18) with performance on the average interest category significantly lower than the low interest category (p =. 004). The rate of false alarms did not change significantly over the simulated night shift when collapsing across book category. Overall, the best keyword performance, as indicated by the highest average keyword hit percent (Figure 2) and lowest number of false alarms (Figure 3), was for the low interest category.

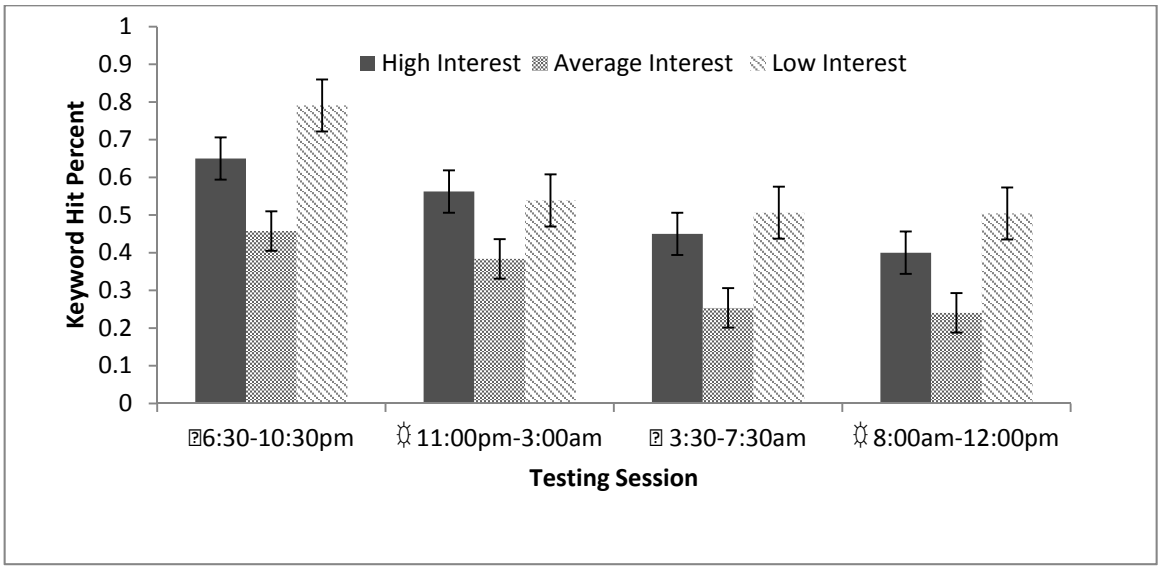

Figure 2. Keyword hit percent performance by testing sessions. Error bars represent standard errors of the mean. High Interest: 7 Habits of Highly Effective People; Average Interest (average of two books): DNA: The Secret of Life and The Americanization of Benjamin Franklin; Low Interest: How the Irish Saved Civilization.

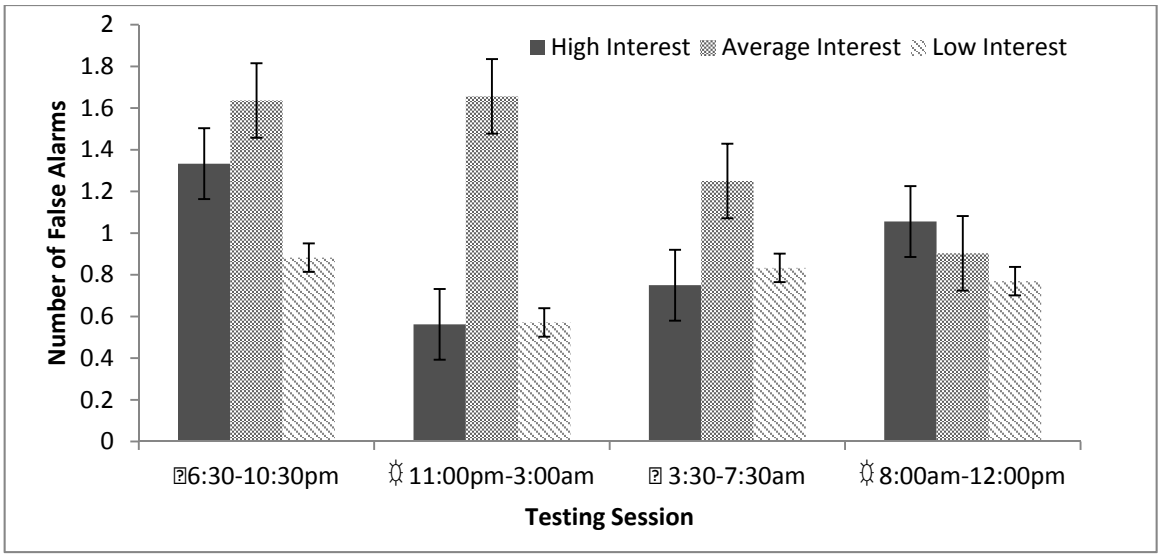

Figure 3. Number of keyword false alarms by testing sessions. Error bars represent standard errors of the mean. High Interest: 7 Habits of Highly Effective People; Average Interest (average of two books): DNA: The Secret of Life and The Americanization of Benjamin Franklin; Low Interest: How the Irish Saved Civilization.

In session one, there was a significant difference among book categories in d' ($F(3,59) = 7.94$, $p = .001$, $\eta_p^2 = .23$) with performance on the average interest category significantly lower than the high interest ($p = .05$) and low interest ($p = .001$) categories. In session two ($F(2,50) = 3.67$, $p = .032$, $\eta_p^2 = .11$) and session three ($F(2,59) = 3.85$, $p = .027$, $\eta_p^2 = .12$), there was a significant difference among book categories in d' but post-hoc comparisons were non-significant. In session four, there was a significant difference among book categories in d' ($F(2,59) = 5.08$, $p = .009$, $\eta_p^2 = .15$) with performance on the average interest category significantly lower than the low interest category ($p = .007$).

DISCUSSION

The results from Study 1 indicate that, as expected, participants experienced decreases in vigilance during a simulated night shift as evidenced by reduced performance on the PVT.

Furthermore, we found decreased performance in Study 1 on main point identification, keyword hit percent, and decreases in sensitivity to the keyword on a dual auditory task. These results indicate that a simulated night shift under sleep deprivation conditions negatively impacts auditory attention and language comprehension. The exploratory results based on the book categories from Study 2 show that performance on a simulated night shift is impacted by the level of interest and difficulty of the auditory material. Summarizing main points and identifying keywords in interesting material were not affected while performance when listening to average interest and less interesting material suffered.

The decrease in the number of correctly identified keywords and decreases in sensitivity to the keyword in Study 1 support our first hypothesis. These results also support previous research suggesting that auditory attention is negatively affected by sleep deprivation (e.g., Lim & Dinges 2010; Roca et al., 2012). The current results are important since many vigilance or attention tasks rely on the use of tones to assess auditory vigilance (e.g., Babkoff, Zukermen, Fostick, & Ben-Artzi, 2005), whereas the current task required participants to attend to specific words. Distinguishing words from other language stimuli provides a more realistic work-like condition where many individuals are required to process language input. Moreover, the results from Study 1 further supported our first hypothesis in that main point identification decreased across a simulated night shift indicating a decrease in language comprehension over the night. This finding indicates that auditory comprehension can be negatively affected during night shifts, an important consideration for many work environments where accurate language processing is an important element of successful operations.

Although the original intent of our study was to focus on changes in auditory comprehension and keyword detection on a dual auditory task during a simulated night shift, we

also found that the content of the auditory material had an impact on performance. Applying the book categories from Study 2 to the data from the simulated night shift in Study 1 suggest that when auditory material is interesting and less difficult, main point performance decreases while vigilance performance does not necessarily suffer. However, when the auditory material is less interesting and more difficult, vigilance performance improves while main point performance decreases. These results support our second hypothesis that the characteristics of the auditory material would affect performance during a simulated night shift. Thus, although some evidence suggests that vigilance is consistently hindered by sleep deprivation (Lim & Dinges, 2010; Harrison & Horne, 2000), the current results suggest that the effect on auditory vigilance depends on the characteristics of the task.

It is interesting to note that there was decreased main point performance with a higher keyword hit percent on the low interest and high difficulty passage. This suggests that participants could have used a trade-off strategy when completing the dual task for the low interest passage and supports research indicating that dual tasks using the same perceptual process could create a processing bottleneck (Liu, Doong, Hsu, Huang, & Jeng, 2009). It is feasible that, participants in the current study may have given up on trying to understand the content of the low interest/high difficulty passage and focused on the task of responding to keywords. This supports previous research suggesting that perceived difficulty can negatively affect cognitive processing in dual tasks (Bryce & Bratzke, 2014) and that sleep-deprived persons will select less difficult tasks when provided the opportunity (Engle-Friedman, et al., 2003). Selectively increasing effort on the keyword task could have resulted in the higher keyword hit percent (although it still decreased significantly across the night) for the low interest category material.

Participants performed best on identifying main points and relatively high on recognizing keywords on the high interest material. In contrast, when the content of the task became subjectively less interesting and did not encourage sufficient attention, performance increasingly suffered. These findings align with the Controlled Attention Model which holds that performance is better maintained in sleep-deprived individuals for tasks that are more intrinsically engaging and interesting (Pilcher, Band, et al., 2007). Furthermore, the results support a connection between attentional mechanisms and the broader construct of self-control (Hanif, et al., 2012; Pilcher, Geldhauser, Beeco, & Lindquist, 2013; Pilcher, Morris, Donnelly, & Feigl, 2015) and resource allocation (Lim, & Kwok, 2016). For example, participants in the current study could have focused on completing the keyword task regardless of the interest level of the material through enhanced self-control. As such, difficulty controlling attention and initiating the necessary levels of self-control can help explain the current results on a dual task that contains both a vigilance/attention component as well as the more cognitively demanding skill of language comprehension.

The present results also contribute to an additional research area examining the cognitive mechanisms behind sustained attention and resource allocation. There is debate in the literature as to whether attention lapses are due to cognitive underload or cognitive overload (Helton & Warm, 2008). Underload theorists maintain that attention lapses occur more often in boring and monotonous conditions (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) while overload theorists maintain that attention lapses occur more often under higher cognitive load (Head & Helton, 2012). The current results suggest that auditory passages that are of low subjective interest but increased difficulty resulted in improved vigilance as seen in the performance on the keyword task but worse performance on the main points task. Because this was a dual task, as

previously mentioned, it is possible that the participants chose the easier keyword task but sacrificed comprehension. As such, the present results support the research suggesting that vigilance is dependent on mental resources and resource allocation (Head & Helton, 2014). Future research could be designed to specifically examine sustained attention on a dual auditory task such as the one used in the current study to better understand the possible connections between mental resources and sustained attention.

These results have important implications. Insufficient sleep (Hublin, Kaprio, Partinen, & Koskenvuo, 2001; Thorley, 2013) and shiftwork (McMenamin, 2007) are prevalent in modern society. To help address this issue, research on simulated night shifts can be used as models to document the possible negative effects of shiftwork on health and performance (e.g., McCubbin, Pilcher, & Moore, 2010; Pilcher, Vander Wood, & O'Connell, 2011; Sauer, Wastell, Hockey, & Earle, 2003). Furthermore, working night shifts or other shiftwork schedules that result in increased sleep deprivation have been shown to have adverse consequences on health and performance (Hayes, et al., 2006; McClelland, Switzer III, & Pilcher, 2013). Failures in communication and language processing under night shift and sleep deprivation conditions could be particularly detrimental in many work environments resulting in serious errors.

The current results suggest that well thought out coping strategies could be implemented to help improve performance during night shifts. An important approach is to be more aware of the type of tasks that night shift workers are expected to perform and at what time of the night they are performing the task. Managers and workers should expect working at night to create problems with vigilance and sustained attention. One way to help workers cope is to implement methods that could keep necessary tasks more interesting. Another method is to provide a means for the workers to stay better engaged and more focused. It could be possible in some work

settings to select tasks that are intrinsically more interesting to complete during night shifts or potentially provide methods for night workers to remain more attentive perhaps through light physical activity. More research is needed that examines methods that may help alleviate lack of engagement and attentive behavior during night shifts.

The present study had several limitations. First, the study design lacked a control group. Without a control group, it is difficult to eliminate the possibility that some results could be due to the combination of the effects of repeated testing and increasing sleep deprivation during the simulated night shift. However, a true control group would be difficult and costly to institute. To create a control group that is rested during a simulated night shift, the group would require a complete inversion of their endogenous circadian rhythms; something few people would be willing to attempt. As such, while the effects of repeated tasks versus sleep deprivation cannot be definitively distinguished in the present research, the current design imitates actual shiftwork in modern society and is realistic in application. A second consideration is that caffeine consumption was not allowed during the sleep deprivation study. This is common practice in sleep deprivation and simulated shiftwork studies since the effects of caffeine on each individual would depend on the individual's daily consumption and the individual's tolerance for caffeine. Future studies could be designed to examine the potential effects of caffeine consumption during simulated shiftwork. A third limitation is the identification of different keywords for each auditory passage to create an auditory vigilance task where the keywords occurred infrequently, yet often enough to create a useable data set. Since the purpose was simple recognition of the keyword, it seems unlikely there would be a difference in response rates due to the individual keywords. Future studies can be designed to investigate whether different keywords from auditory passages could affect response rates. Another consideration is that the tasks were

counterbalanced within each testing session to control for possible order effects. This naturally led to some tasks occurring earlier or later in the four testing sessions leading to a possible effect of time of administration on task performance. Given that the design of the current study was to simulate night shift work there was no way to control for the effect of time on task administration and administer multiple tasks throughout the night while controlling for possible order effects. Future studies could be implemented that used only one task and then test for the possible effect of time of administration on task performance; however, these studies would no longer be imitating a night shift condition where workers are completing tasks throughout the night. Last, the differences in interest and difficulty within the audio passages was not tested until Study 2, after the completion of the simulated night shift study (Study 1). As such, we did not directly control the content of the four books used in Study 1. However, by applying the book categories determined in Study 2 to the data collected in the simulated night shift in Study 1, we were able to examine the potential effects of task characteristics on auditory language performance during night shifts. Future studies could be designed to administer an auditory task where each person listens to passages of the same interest or difficulty level during a simulated night shift to more thoroughly examine the effects of task characteristics on auditory performance.

CONCLUSIONS

The present study provides insight into how auditory language processing is affected when working a simulated night shift under sleep deprivation conditions. We demonstrated that working at night negatively impacts auditory attention and language comprehension and provide exploratory results on how the effects vary based on the characteristics of the auditory material.

Auditory comprehension suffers during a simulated night shift, particularly when the information is less interesting and more difficult to understand. Because language comprehension is vital in the workplace and in human interactions, further research using language-based tasks is needed to better understand the impact of working at night on auditory language attention and comprehension. In addition, future research could address the complexity of language comprehension by examining both the type of task and content within the task. The current results also suggest that it is important to consider how regulatory and attentional mechanisms may impact different types of tasks when working at night. Finally, monitoring performance and making an effort to keep tasks interesting and less difficult could help maintain higher performance levels when individuals are required to work during the night under sleep deprivation conditions.

KEY POINTS

- Auditory attention and language comprehension on a dual task significantly decreased across a simulated night shift under sleep deprivation conditions.
- The content of the auditory material affected performance where interesting and easy passages resulted in better performance at night while less interesting and more difficult passages resulted in a decrease in performance.
- Better integrating the concept of self-control and resource management when considering how to best adapt to working at night could result in better decision making on critical tasks.

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