Is in-Vehicle Background Audio Distracting to Drivers?

A Senior Thesis

Presented in Partial Fulfillment of the Requirements for graduation with research distinction in Speech and Hearing Science in the undergraduate colleges of The Ohio State University

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April 2016

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Abstract

Driving an automobile is one of the most automatized, but also complex tasks completed on a daily basis. Beyond merely operating pedals and a steering wheel, drivers need to maintain situational awareness and respond to unexpected events by other drivers, as well as other visual and auditory signals. Drivers often engage in secondary, non-driving tasks while driving as well, such as listening to music. Some drivers routinely drive in the presence of very high levels of background audio. Previous studies have offered differing conclusions on whether in-vehicle background audio can affect driving behavior, possibly by increasing the driver's cognitive workload. In the present study, nineteen adult participants performed a variety of tasks in the presence of different levels and types of background audio, while operating a simulated vehicle at The Ohio State Driving Simulation Laboratory. Drivers also performed two secondary tasks to assess cognitive workload while driving: performing complicated arithmetic calculations on numbers on billboards placed in unexpected locations in the scenario, and rating the urgency of visual and auditory warning signals presented at varied intervals in the scenario. Measures of driving performance included speed, following behavior, steering smoothness, and lane keeping capabilities. Results showed that increased audio levels decrease the perceived urgency of warnings, and increase the number of errors in the arithmetic task. Driving performance was not impacted, suggesting that high audio levels reduce overall situational awareness and increase cognitive workload.

Acknowledgments

I would like to thank my research advisor, Janet M. Weisenberger, for her endless encouragement and for the wisdom that she has shared that I will take along with me well after this project is over. I would also like to thank Thomas Kerwin, Patrick Veith, Tyler Whitlock, Kevin Smearsoll, and all other employees at The Ohio State University Driving Simulation Lab for investing their time in helping me complete my project. My thesis could not have been completed if it were not for all of the countless contributors who helped me along the way.

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Chapter 1: Introduction and Literature Review

Universally, driving an automobile is one of the most mundane, but at the same time complex tasks completed on a daily basis (Thorslund et al., 2013). The universal nature of driving is generating increasing amounts of attention to how this complex task is affecting overall safety. Many aspects of driving a vehicle may seem automatic and "mindless," but if driving were so effortless then there would not be so many fatal accidents. It is crucial to identify what factors can make this ordinary task so perilous. In an ideal driving situation, the driver would buckle into the driver's seat, shift the vehicle into drive, and commute on his or her route with little to no distraction. Yet, in modern vehicles this is not a realistic expectation. Some of the immediate tasks the driver needs to be equipped to handle may include lane keeping, abiding to speed limits, watching for unexpected events by other drivers, and responding to auditory signals. In addition, infotainment systems offer drivers the option to listen to music, engage in navigation systems, talk on the phone, monitor emails, etc. Operating a vehicle can be such a convoluted task that it is essential to discover how we can make driving a little bit safer.

Automobile accidents arise from a myriad of causes; however, secondary tasks involved seem to be a recurring theme in many of the mishaps. Brodsky and Slor (2013) affirm this by citing, "secondary task distraction is a contributing factor in at least 23% of all accidents (p. 392)." When did driving a car turn into a balancing act of so many accessory distractions? Hickson et al. (2010) contend that in-vehicle systems have become increasingly loaded with intricate navigation and entertainment systems, potentially burdening the driver's attention. In turn, this strain on a motorist's attention diverts him or her from the primary task at hand, which is simply driving to an intended destination.

The actual loss of control of the vehicle, as researched by Thorslund et al. (2013), arises when "the demands of the driving task exceed the driver's capability (p. 113)." Evidence has shown how detrimental these secondary tasks can be, so it is long overdue to identify why and how these demands cause such a heavy load on the driving task.

The ultimate reason why these auxiliary tasks are so damaging is the increase in cognitive workload that they induce. Wang et al. (2015) argue that events such as "visual complexity, heavy traffic, and parked cars pulling out" all in some way increase mental load (p. 261). Thorslund et al. (2013) state that the act of driving is a cognitive and controlled task on its own and so by adding secondary tasks, the risk for drivers is escalated that much more. They describe the driving effort as dynamic with a constant shift between low and high cognitive demands, changing in a matter of seconds. The secondary tasks imposed by high-tech infotainment systems (including mobile phones and navigation systems) are some of the components causing this drastic increase in mental workload while driving, consequently increasing the risk of distracting the driver from the primary task (Thorslund et al., 2013). These secondary tasks have all been associated with eyes off the road and only one hand grasping the wheel (Brodsky and Slor, 2013). When the increase in cognitive workload causes a driver to shift attention away from the fundamental task at hand for even a few seconds, there is opportunity for catastrophe.

One of the principal secondary factors affecting cognitive workload for drivers is music. Of all the secondary tasks that motorists engage in, listening to music or the radio is the most prevalent (Unal et al., 2013). Because of its prevalence, it is important to investigate the impact of music on the driving task. Research by Brodsky and Slor (2013) indicates that when drivers are listening to music in their automobile they actually feel "inside" the music. Drivers were said to construe their driving experience as 'impenetrable,' so it is logical that most drivers do not realize how their driving is impacted adversely or whether the music is creating an unsafe environment (Brodsky and Slor, 2013). Most individuals do not consider how the genre of music they select can influence their driving behavior. Brodsky and Slor (2013) note that not only can music match the mood of a journey, but also it can relax drivers. In some past research, music was cited as countering monotony and drowsiness, providing an effective method to stay alert (Brodsky and Slor, 2013). Consequently, after these research studies were done, insurance companies began endorsing the use of music in the vehicle, presuming the effects were nothing but favorable (Brodsky and Slor, 2013). However, some studies suggest that music in the car may actually be doing more harm than good.

Brodsky and Slor (2013) observed that "the greater structural complexity of the music, the larger the effects on the critical tasks necessary to safely operate a motor vehicle," thus arguing that complex music increases cognitive workload (p. 383). Regarding tempo, not only was it ascertained that up-tempo music causes more at-risk driving behavior, it was also found that up-beat music can alter perception of passing scenery and "increases acceleration, cruising speed, and traffic violations" (Brodsky and Slor, 2013, p. 383). In terms of mental load, research has shown that listening to auditory information worsens performance (Hickson et al., 2010). In-vehicle listening provides favorable conditions for distraction that can result in "driver miscalculation, inaccuracy, driver error, traffic violations, and driver aggressiveness," so audio should be used with utmost discretion (Brodsky and Slor, 2013, p. 392).

On the other hand, there are some instances where listening to music can be quite advantageous and possibly even life saving. In-car radio can be most appropriate during monotonous, low-complexity driving conditions. Unal et al. (2013) found that in these circumstances, music provides the added external stimulation needed to counter boredom and satisfy the lack of arousal. Drivers cope with the increased task demand of listening to music by developing compensatory strategies to protect their vehicular performance (Unal et al., 2013). In one experiment, Unal et al. (2013) discovered that car-control performance was enhanced with the presence of a secondary task compared to no added secondary task. Nonetheless, it is important to note that this effect was observed in low-complexity driving situations and might not generalize to more complex driving. Music adds needed stimulation for repetitious driving, but may not be appropriate for more complex driving because of the increased demand on cognitive workload.

Brodsky and Slor (2013) suggested that the discrepancy in results argued for more research into the effects of background audio in the vehicle. Because automobiles are one of the most popular locations for listening to music, they argued that it is imperative for more research to be conducted analyzing how music is impacting the driver. They noted, "traffic researchers and accident investigators are not mindful of risks associated with music (p. 383)." Brodsky and Slor suggest that any competing stimulus affecting driver alertness, position on the road, speed control, reaction times, etc. should be handled as a source of distraction. It appears that driving researchers and more importantly, drivers themselves may underestimate the risk factor of music in the automobile.

An additional secondary task involved with driving is perceiving, comprehending, and reacting to warnings presented by the vehicle. The auditory modality has been used for a long time "to convey anything from warnings to status messages to more recent social notifications, and is an ideal modality in which to present a wide array of alerts, due mainly to its flexibility" (Lewis et al., 2014, p. 2078). An important issue with auditory warnings, however, is a high chance of ambiguity if the warning is not selected well. Enigmatic sounds can increase one's mental load, making the driving task even more burdensome to complete (Lewis et al., 2014). Lewis et al. (2014) found that sounds with some acoustic components associated with high-perceived urgency and other acoustic components associated with low-perceived urgency are ambiguous to drivers. This in turn creates a risky driving situation, causing the driver to respond more slowly and even react incorrectly. Lewis et al. (2014) concluded their study by contending; "it is possible to define acoustic characteristics of sounds in an in-vehicle context in order to facilitate the design of intuitive, unambiguous alerting systems (p. 2082)." To prevent auditory signals from becoming a distraction and adding to cognitive workload, it is vital that they be chosen with the background noise environment in mind rather than just being arbitrarily assigned (Stanton and Edworthy, 1999). Auditory signals need to be selected carefully because the mere presence of a signal will not guarantee lucidity and if the warnings are too loud or sound too frequently then they will also be unsuitable, not fulfilling their job (Stanton and Edworthy, 1999). Because auditory warnings are the most prevalent way of alerting drivers to potential accident situations to which the driver must counter promptly, it is imperative that more research be done to ensure the accurate perception of the warning signals presented (Lerner et al., 2015).

In some sense, the presence of high levels of background audio in the vehicle mimics the effect of hearing impairment. Hickson et al. (2010) has shown that there is a link between hearing impairment and driving difficulty, particularly in the elderly population. Notably, they found that people who have some sort of hearing impairment have been shown to be more susceptible to distraction and potential driving impairment. In their study, the participants with a hearing impairment had their driving compromised more when trying to undertake a secondary task while in the vehicle, as measured by observing driving performance in the presence of a visual or auditory distracter. Hickson et al. (2010) suggested that the elderly in particular should make an extra effort to eliminate or at least reduce in vehicle distraction, including "listening to the radio, conversations with passengers, looking at navigation systems, and mobile phone use" so as to not risk injury (p. 1101). Ultimately, their findings indicated that there indeed was a correlation in elderly people between moderate to severe hearing impairment and unsatisfactory driving when distractors were present. Drivers without a hearing impairment may mask other acoustic stimuli by playing music at excessive levels, thus essentially creating the same scenario as in hearing impairment – i.e., lack of awareness of auditory stimuli in the environment.

The impact of high levels of background audio on the perception of auditory warnings is one manifestation of this concern. One study of the perception of auditory signals inside the car was done by Lerner et al. (2015) and is titled *In-Vehicle Noise Alters the Perceived Meaning of Auditory Signals*. This article argues that some auditory warnings can be more important than others, contingent on the context. The objective was to ensure that critical crash warnings are the most easily discriminated. Lerner et al. (2015) noted that previous research done on the topic of auditory crash warnings was done solely under benign ambient noise, which is not realistic for a driving scenario. Their hypothesis was that noisier ambient conditions are the ones that should be tested, since in those conditions the accurate perception of crash warnings is particularly crucial. As indicated by their experiments, "the resistance of an auditory signal to noise effects is not an attribute of the signal alone, but rather includes its interactions with the specific characteristics of the background noise (p. 411)." They demonstrated that it is not sufficient to compare "low" and "high" background noise, because depending on the signal, one type of noise may cause more signal degradation.

A study by Silveous (2015) also evaluated the effects of background audio on drivers' performance. She tested the drivers' situational awareness by having them perform arithmetic tasks on passing billboards while driving, and also asked her participants to rate different warnings based on urgency. Inside the vehicle, Silveous presented participants with no music, soft rock music, or hard rock music at three audio levels while completing each task. Silveous found an effect of background audio on driving speed, with higher audio levels producing higher speeds. In addition, she reported that participants gave lower urgency ratings to warning signals at higher audio levels. However, Silveous observed no effect of background audio on performance in the billboard arithmetic task. Situational awareness was high for all participants at all audio levels possibly because the arithmetic task was too simple and also possibly because the billboards were evenly spaced in the scenario and thus could be easily anticipated. Participant situational awareness was assessed in the present study as well. However, participants were asked to rate perceived urgency of warning signals interspersed with the billboard task, so the tasks were less predictable in occurrence. The billboards occurred more sporadically in the driving scenario, and the arithmetic operation was more demanding.

Another possible confound in the Silveous study was the fact that the maximum background audio level presented was 76 dBA. In actual driving, drivers routinely adjust the audio to much higher levels of sound. Brodsky and Slor (2013) found that "the average reproduction volume of music heard in the vehicles was 85 dB (p. 389)." Thus, Silveous may not have observed a true representation of the impact that background audio had on the driving task. Finally, it is possible that the rather non-demanding scenario used in the Silveous study did not tax the driver's cognitive resources in any way. As noted, previous work with very simple driving scenarios has not shown effects of background audio.

The present study was designed to investigate how in-car audio affects different aspects of driving and specifically to address possible issues with the results reported by Silveous (2015). Participant situational awareness was assessed in this present study as well. However, participants were asked to rate perceived urgency of warning signals interspersed with the billboard task, so the tasks were less predictable in occurrence. The billboards occurred more sporadically in the driving scenario, and the arithmetic operation was more demanding. The interleaving of the warnings task with the billboard arithmetic task was designed to create a more realistic way of increasing driver workload and assessing situational awareness. In addition, in the present study, the participant selected his or her own audio level during a practice drive to match the level they usually listen to in their own vehicle. This level was used as a baseline, and background audio was presented at baseline, baseline minus 10 dB, and baseline plus 10 dB. Finally, a slightly more challenging driving scenario was constructed that included some unexpected events, such as a car pulling out in front of the driver. Measures of driving performance included speed changes, following behavior, and lane keeping capabilities.

It was hypothesized that listening to music at a higher level would result in underestimation of warning urgency, poorer performance on the billboard arithmetic task, and poorer performance on the driving measures. Faster tempo music was expected to impact primarily driving measures, producing less safe driving behavior.

Chapter 2: Methods

Participants

The Ohio State University Institutional Review Board, IRB Protocol number 2013B0050, approved this study. There were twenty participants in this study, one of whom developed simulator motion sickness, so had to discontinue. The participants that were able to complete the study included ten men and nine women between the ages of 18 and 25 years. All participants received $40 as compensation for their time. The participants were recruited via word of mouth. A quick auditory screening using the Mimi Hearing Test Application was performed for each participant in a quiet room using headphones. Additionally, a vision screening using a Snellen Eye Chart was performed with participants sitting 20 feet away from the chart reading aloud the smallest row of characters they could see. By these measures all participants had normal hearing and normal or corrected-to-normal vision.

Simulator Equipment and Stimuli

A Realtime Technologies Inc. (RTI) driving simulator was used for this experiment. This simulator includes a 2010 Honda Accord cab mounted on a 6 degree of freedom motion-base platform, with a cylindrical projection screen wrapping around the vehicle at 260° field of view. Five projectors provided a seamless visual representation of the driving scenario. An additional rearview screen provided rearview information and two LCD screens mounted in the side mirrors provided side-mirror views. The motion-base platform moves in six degrees of motion, making the simulated drive feel similar to a normal driving experience. Four video cameras were mounted to the interior of the vehicle, to capture both the participant and the simulated scenario. The interior of the car is that of a Honda Accord including a gas pedal, a brake pedal, a shifter knob, a turn signal, and a steering wheel. A speedometer was displayed on the front projector for the participant's use. External audio speakers were mounted on the cylindrical screen and provided audio cues about the vehicle's motion (acceleration and deceleration, wind noise, etc.) Music was presented via the vehicle's audio system and speakers.

SimCreator software by RTI was used to create the simulated scenario. The scenario created imitated a two-lane highway with a relatively high level of traffic. Twenty billboards were added into the scenario, placed at random intervals throughout the map. All of the billboards were presented on the right side of the road, with a different set of four numbers displayed on the front and back of each one.

Fifteen warning signals were presented during experimentation. These were chosen from a larger set used in several previous studies of warning urgency in the lab. Thus, a good estimate of expected urgency was available. Each signal had both visual and auditory components. The visual components were squares displayed on the vehicle's dashboard varying in color (red/yellow), size (.8125 in^2 or 1.5625 in^2), and duration of illumination (1,000ms, 2,000ms, or repeating). Auditory components (1,000 Hz tones) were played through the vehicle's audio system and varied in duration of sound (500ms, 1,000ms, or repeating), and level (55 dBA or 65 dBA as measured from the position of the driver's head with a hand-held sound level meter). Table 1 shows the characteristics of each warning signal. Signals were chosen from a set previously used in the laboratory for other studies, and were known to vary in perceived urgency.

Table 1

Characteristics of Warnings

Visual				Auditory		
Signal	**Color**	**Size**	**Duration**	**Volume**	**Duration**	**Expected Urgency**
1	Yellow	.8125 inches	1000ms	55dB	500ms	2.5
2	Yellow	.8125 inches	1000ms	55dB	1000ms	1.5
3	Yellow	.8125 inches	1000ms	55dB	Repeating	1.75
4	Yellow	.8125 inches	2000ms	55dB	500ms	1.5
5	Red	.8125 inches	1000ms	65dB	Repeating	2.75
6	Yellow	.8125 inches	Repeating	55dB	500ms	2
7	Yellow	1.5625 inches	Repeating	55dB	500ms	3
8	Yellow	1.5625 inches	Repeating	55dB	1000ms	2.75
9	Yellow	1.5625 inches	2000ms	55dB	Repeating	3
10	Yellow	1.5625 inches	Repeating	55dB	500ms	2.5
11	Yellow	.8125 inches	Repeating	55dB	500ms	2.5
12	Red	1.5625 inches	Repeating	65dB	Repeating	3.75
13	Yellow	1.5625 inches	1000ms	55dB	500ms	2.5
14	Red	1.5625 inches	Repeating	65dB	500ms	3.5
15	Red	1.5625 inches	2000ms	65dB	1000ms	3.5

Background audio consisted of a fixed playlist of songs presented via the vehicle's audio system. The music played during the tasks was presented at three different audio levels: a baseline audio level that the participant chose mimicking the loudness they listen to in their own car, 10 dB above that baseline level, and 10 dB below that baseline level. Level measurements were made with a sound level meter, placed at the approximate position of the driver's head. Ten of the participants listened to down-tempo music and nine of the participants listened to up-tempo music. The average tempo of the down-tempo music was 85 bpm, and the average tempo of the up-tempo music was 155 bpm. Specific music playlists are included in the Appendix.

Procedure

To start, each participant had his or her eyesight tested using a Snellen Logarithmic Visual Acuity Chart placed at a distance of 20 feet. The participant was then instructed to engage in a short hearing test using the Mimi Hearing Test Application on the iPhone. Following these tests, each participant was required to read and sign a consent form before experimentation began. The participant then took a position in the driver's seat and the moderator was seated in the passenger seat alongside the participant for the duration of the test. Assistants in the control room located behind the simulated vehicle were responsible for starting the simulator and controlling the lights. Once the participant became comfortable in the driver seat, he or she began to practice driving for approximately five minutes. This driving practice period gave participants time to get acclimated to the simulator's differences and sensitivities compared to their own vehicles. At this time, the participant was instructed to adjust the volume in the car to what he or she normally listens to in his or her own car. This level was recorded and then used for the actual test.

After completing the practice drive, participants pulled over on the right side of the road to be given test instructions. The participant was notified that there were two different types of tasks that they would be completing during the study. The first task was a warning signal task. When the participant heard or saw a warning signal on the dashboard, they were told to rate the perceived urgency of the warning played through the car's audio system on a scale of 1-5, with one being the least urgent and five being the most urgent. Participants were told to rate the urgency based on the size, color, shape, and sound of each warning. After the participant felt comfortable practicing this task with some practice warnings, the moderator went over the next task.

The second task that the moderator provided instructions for was the billboard arithmetic task. For this task the participant was told to indicate where a billboard was detected. The participant was then told to complete an arithmetic task using the numbers on the billboard. A different task was used for each billboard so that the driver could not anticipate a response. Examples of tasks included, add the third highest number with the lowest number, or subtract the second lowest number from the second highest number. The participant would use the four numbers provided on each billboard to perform the arithmetic. This task was not used to test the participant's mathematical ability, but was used as a proxy for a complex decision making task that a typical driver may make while driving, as well as a measure of situational awareness.

After the two tasks were described, the participant was told to merge back on to the highway and to maintain a constant speed of 60mph. Three different audio levels were played in a random order during the drive, including a baseline audio level that the participant had chosen, 10 dB above that level, and 10 dB below that baseline audio level, all played for about 15 minutes each. Half of the participants listened to up-tempo music while the other half listened to down-tempo music. The research assistants in the control room recorded the participant's answers for both the warning and billboard tasks into an Excel document.

Chapter 3: Results and Discussion

Results were evaluated to examine overall effects of the independent variables of music tempo and audio level on several dependent variables, including billboard arithmetic task accuracy, perceived warning urgency, and measures of driving performance. Analyses were done with an alpha level of .05. Verbal response dependent variables are discussed first, followed by the driving variables.

Warning Urgency Ratings

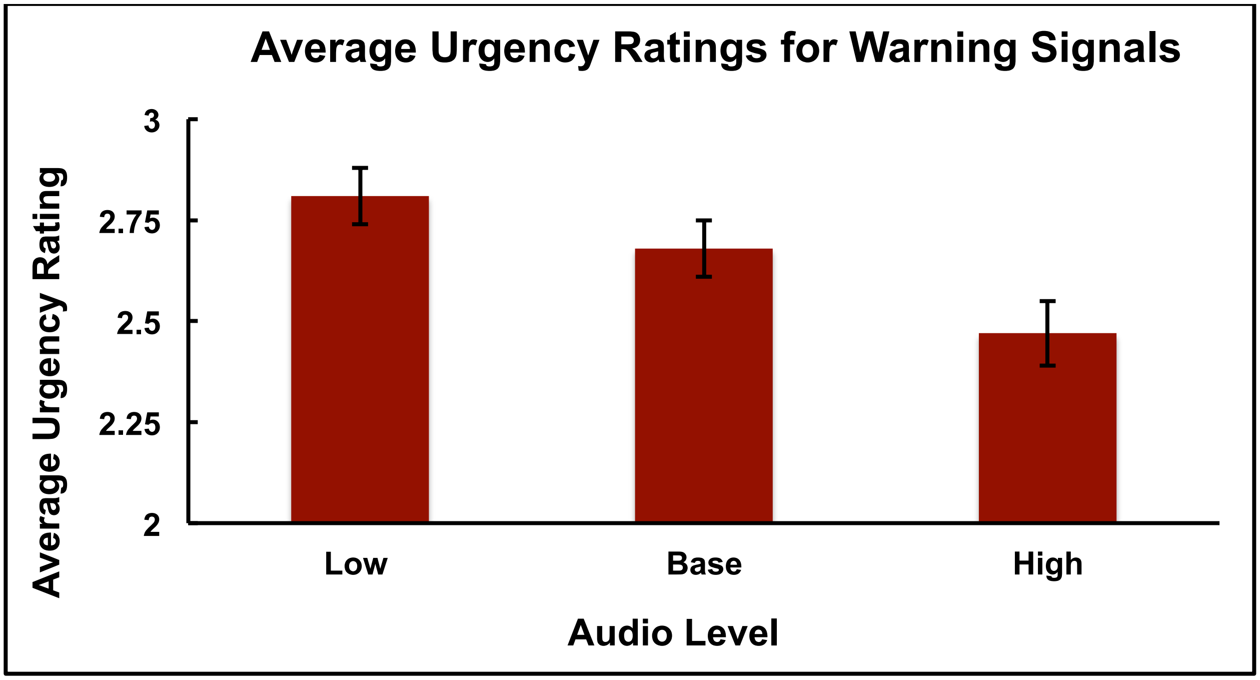

Figure 1. Average urgency ratings for all warnings, as a function of music level.

Figure 1 shows the average ratings of urgency for the 15 warning signals. The results indicate that the rated urgency of warning was lower at higher audio levels. To assess the significance of this effect, a two-factor, mixed model analysis of variance (ANOVA) was performed, with music tempo as a between-groups factor and audio level as a within-groups factor. A significant effect of audio level was found, F(2,34) = 10.35, p=.003. No significant effect of tempo or interaction effect was observed.

It is logical to assume that the higher audio levels impacted audibility of the auditory component of the warning signals. This could be investigated by determining whether the underestimation effect was seen only for 55 dB warning signals, or was also present for signals with a 65 dB auditory component. Figure 2 shows the mean urgency ratings for each of the 15 warning signals at each background audio level.

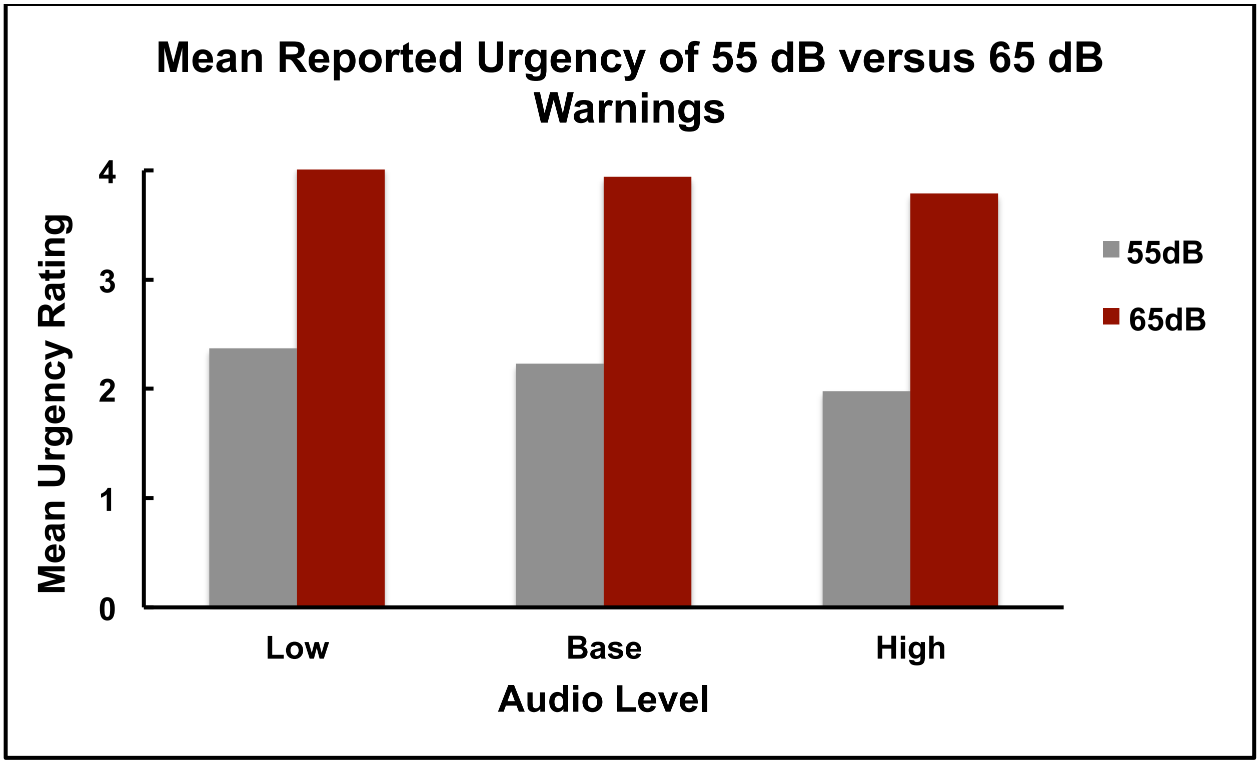

Figure 2. Mean reported urgency of 55 dB and 65 dB warning signals across all three audio levels.

These data indicate that underestimation of urgency occurred for signals at both the 55 dB level and the 65 dB level. From the lowest audio level to the highest audio level, there was a decrease of .24 in perceived urgency for the 65-dB signals and a decrease of .39 for the 55-dB signals. Thus, although the decline was greater for the 55-dB signals, both signal levels were impacted. It is important to note that each warning signal had a visual component as well as an auditory component. This makes it more remarkable that some warning signals were missed completely. It also suggests that the effect was not purely auditory masking, but also included a cognitive workload component.

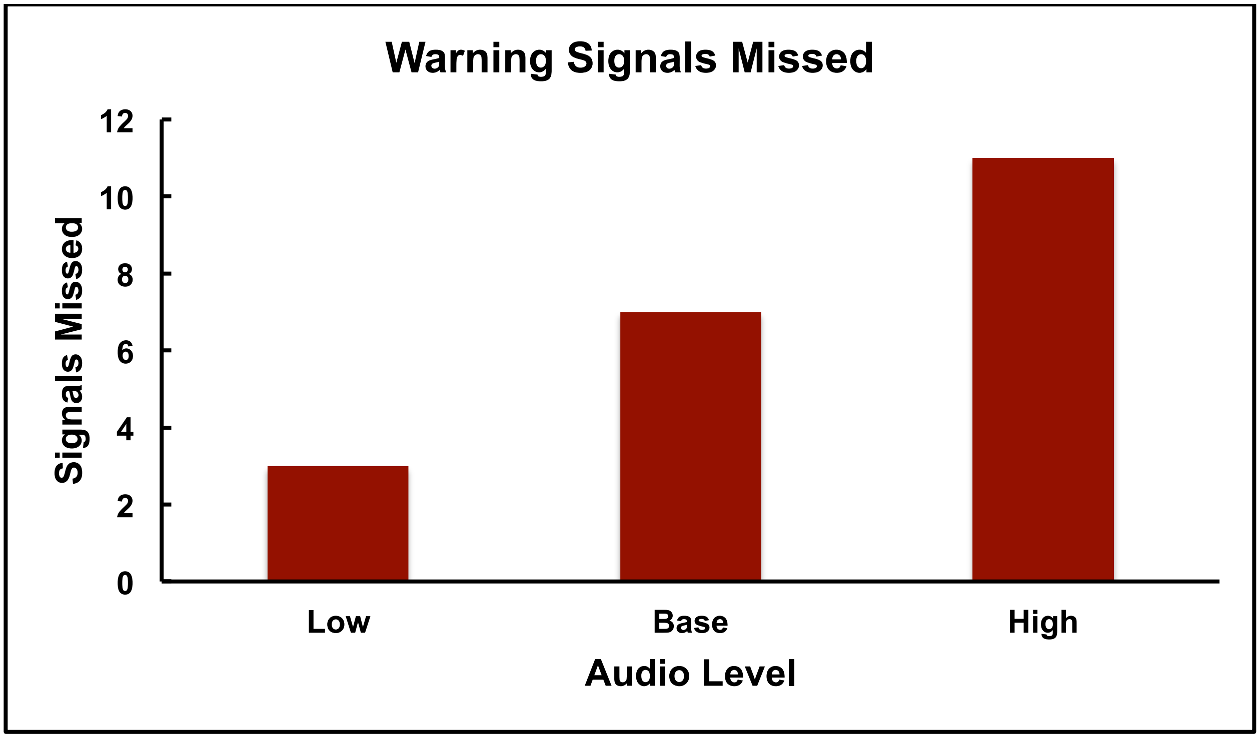

Figure 3. Number of warning signals missed across all three audio levels.

Figure 3 shows the total number of warning signals that were missed across the three audio levels, summed across all participants. As can be seen, as audio level increased, the number of warning signals missed increased as well. A chi-square analysis was used to determine whether the number of missed signals differed from expectations. A significant effect was observed, $\chi^2(2) = 4.57$, $p=.03$, indicating that significantly more signals were missed at the highest audio level.

The fact that some signals were missed entirely suggests an effect on attention allocation and situational awareness. As the level increased, participants may have missed signals because of higher levels of cognitive workload, rather than simply lack of audibility.

Warning signals need to be designed and presented carefully so that drivers do not underestimate or miss them entirely. Further work might test a broader distribution of visual and auditory warning signals to get a better idea of whether this effect is purely one of audibility, or whether cognitive workload factors may also play a role.

Billboard Arithmetic Task

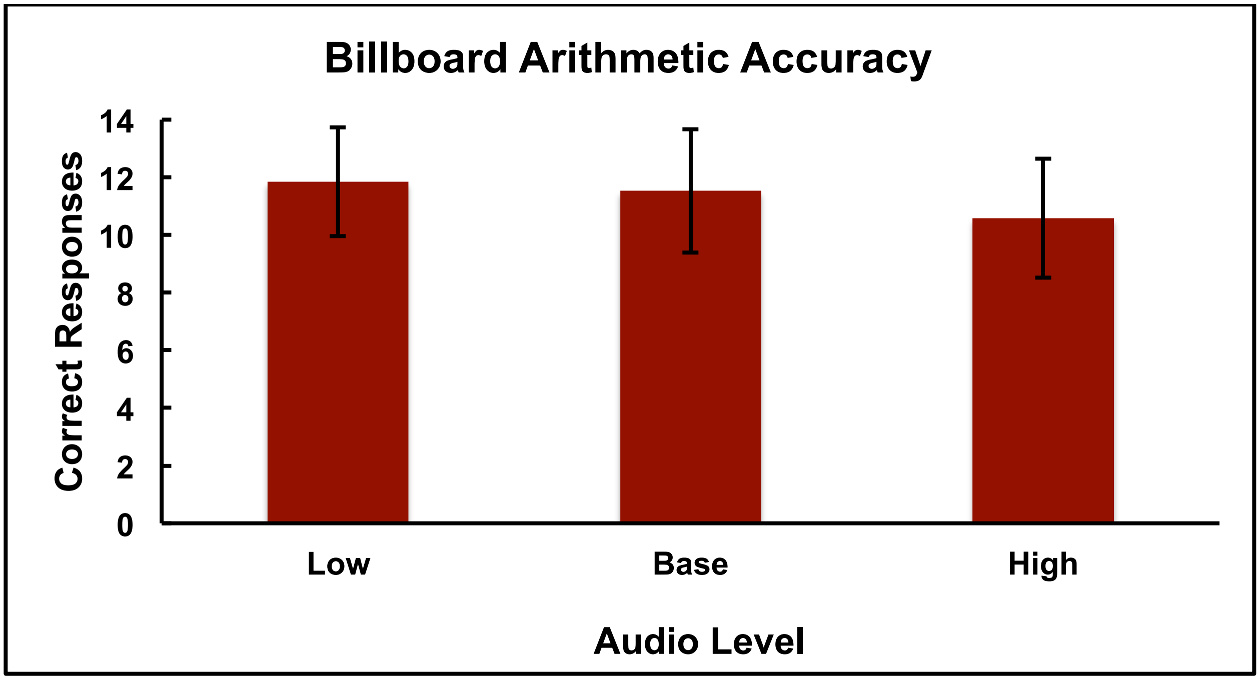

Figure 4. Correct responses on billboard arithmetic task across all three audio levels.

Figure 4 shows the total number of correct responses on the billboard arithmetic task across levels of background audio. A two-factor, mixed model analysis of variance was performed to assess significant effects, with tempo as a between-groups factor and audio level as a within-groups factor. The analysis shows that participants were significantly less accurate on the billboard arithmetic task at higher audio levels, F(2,32) = 5.1, p =.01. No significant tempo effects or interaction effects were found.

The billboard arithmetic task was used as a proxy for any time-pressured, complex decision making task that drivers might need to perform while driving. Detection of billboards gives a measure of overall situational awareness in the driving scenario. As with the warning task, some billboards were missed completely and were scored as incorrect responses.

Because more billboards were completely missed as audio levels increased, it appears that overall situational awareness decreases as the level of audio increases. Also, because there were fewer correct responses with the billboard task at the higher audio levels, it is possible that high levels of audio may affect people's ability to make rapid executive decisions.

Gender Effects

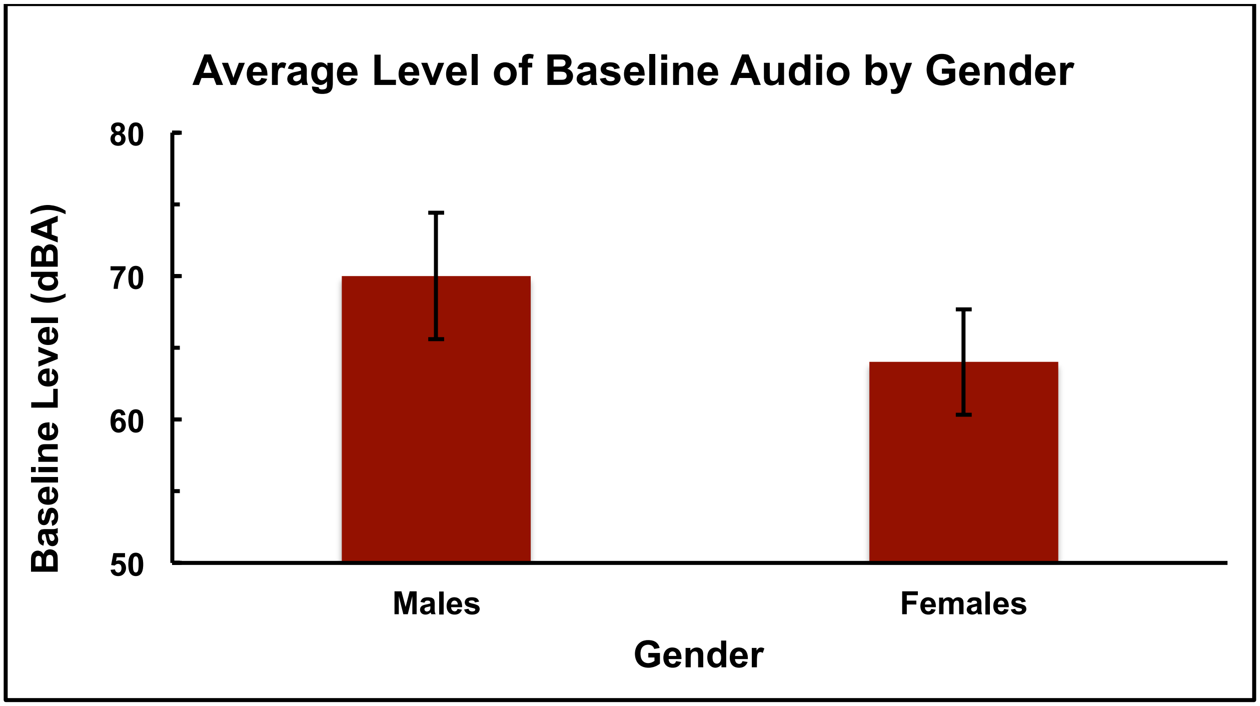

Figure 5. Baseline audio level chosen by gender of participant.

Figure 5 shows differences in the level of background audio selected by participants by gender. Results indicate that males chose significantly higher levels of baseline audio than females, t(18) = 3.2, p=.003. The difference in participant-selected mean baseline audio level was approximately 6 dB, which indicates a comparative doubling of sound intensity between genders.

This analysis was not part of the initial hypotheses of the study, but was an interesting finding nonetheless. Further work could be done to determine if this difference in preferred baseline audio also correlates with other aspects of driving or cognitive task performance in the vehicle.

Driving Performance Measures

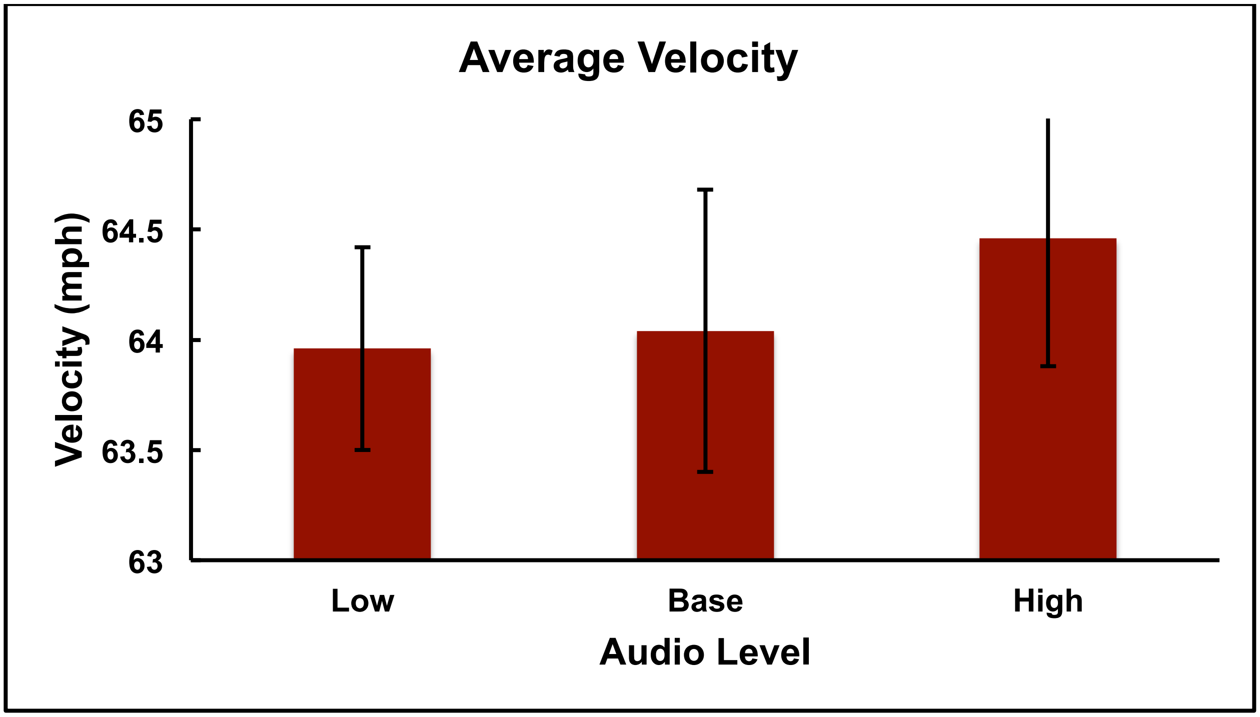

Figure 6. Average velocity of all participants across all three audio levels.

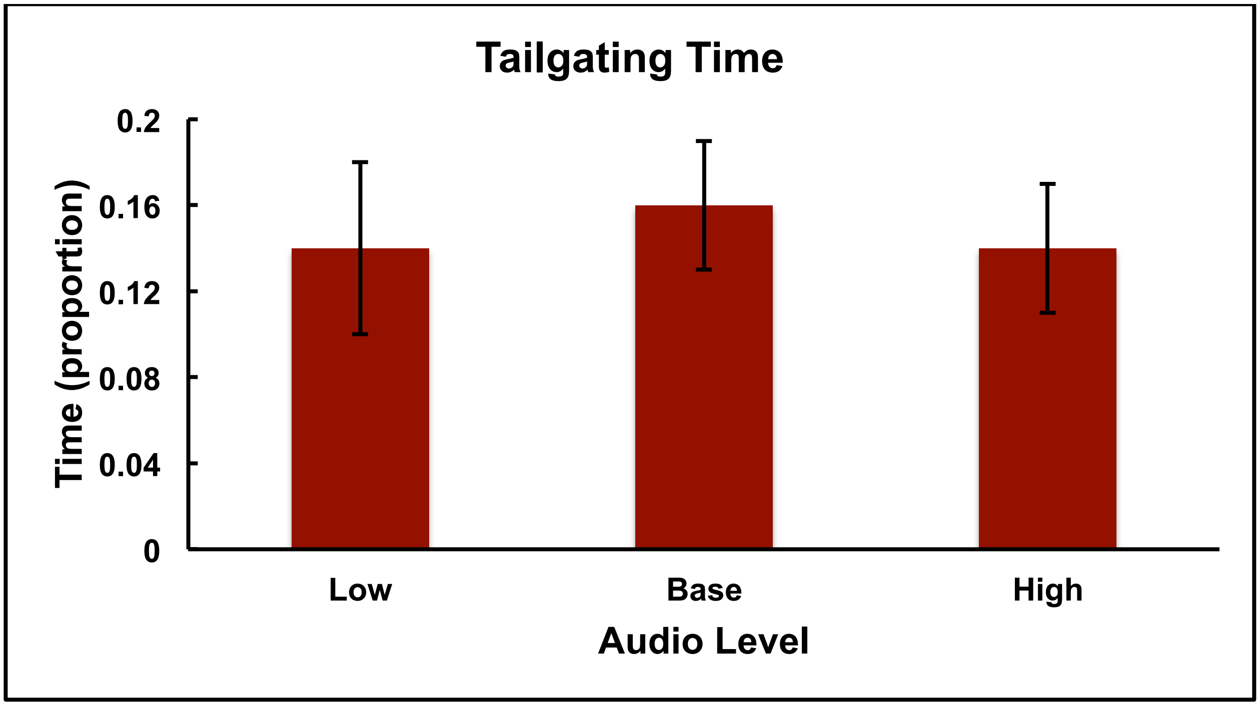

Figure 7. Percent of time spent tailgating with a two second rule across all audio levels.

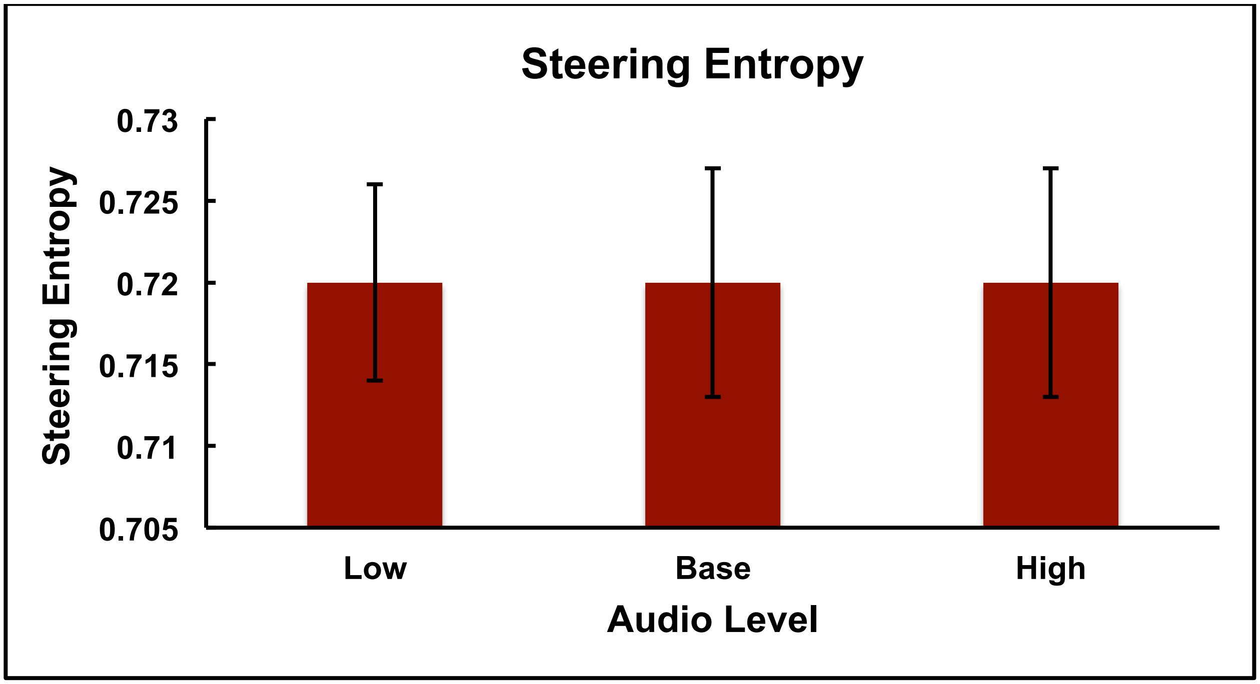

Figure 8. Steering entropy of all participants across all audio levels.

Three measures of driving performance were also examined for possible impacts of background audio: average speed, percentage of time spent tailgating, and steering entropy. Average speed was measured by averaging velocity in miles per hour across the entire scenario for each participant. Tailgating percentage was defined as the percentage of total driving time during which the participant maintained a stopping distance of less than two seconds from the vehicle in front of him/her. Steering entropy is a measure of predictability of the steering trajectory. Used in some studies of driving distraction, steering entropy indicates the "smoothness" or "jerkiness" of steering. High values of steering entropy indicate smoother steering behavior, whereas low values of steering entropy indicate a driver with more erratic steering behavior.

Figures 6, 7, and 8 show the values of these variables across levels of background audio. Inspection of these figures suggests no significant effect of audio level. Analysis of variance results for each variable confirmed this, showing no significant effect of tempo or audio level and no significant interactions. This result was somewhat surprising given the significant effect of audio level on driving speed reported by Silveous (2015). Although there was a trend in this direction in the present study, it did not reach statistical significance.

It appears that background audio does not impact the more mechanical aspects of driving, at least in the present study's driving scenario. The results confirm those of Unal et al. (2013), who did not observe that background audio had any effect on driving performance. Brodsky and Slor (2013), however, found the opposite effect. In addition, other studies of music tempo have shown effects on speed and other driving measures. It is possible that the tempo differences between the music selections in the present study were not sufficiently large to show a tempo effect, and future studies could explore music selections that showed a greater tempo variation. Alternatively, it is possible that the driving task used in the present study, although more challenging than that used by Silveous (2015), may not have taxed the driver's driving skills sufficiently to show an effect of background audio. Future work could investigate driving scenarios with more challenging episodes, such as pedestrians stepping into the roadway, vehicles running stop signs at intersections, etc.

Chapter 4: Summary and Conclusion

Overall, the results of the present study indicate an impact of background audio level on cognitive workload and situational awareness while driving. These effects were manifested in both the warning signal urgency task and the billboard arithmetic task. The results show that as audio level increased, perceived urgency of warnings decreased. Further, more warning signals were missed altogether as audio level increased. This decrease in perceived urgency and increase in missed warning signals occurred despite the fact that the warning signals had visual as well as auditory components. Since visual signals were being missed as the audio level increased, some subtle effect on cognition is likely. It is possible that the increase in missed warning signals is also an indication that, as audio level increases, drivers are affected in their attention allocation as well.

In the billboard arithmetic task, billboard detection was used to observe participants' situational awareness capabilities. The arithmetic on the billboards was used as a proxy for a complex executive decision making task that drivers need to be equipped to make while driving. Results showed that as the level of audio increased in the vehicle, overall situational awareness decreased, given that more billboards were missed completely when the audio level increased. Participants missed more of the arithmetic answers as the audio level increased as well. This is important to note because it tells us that high levels of audio affect people's ability to make rapid executive decisions.

A final observation concerned the baseline levels of music that men listened to compared to women in the present study. Men chose to listen to their music in the car at a level significantly higher than the level that women chose. This choice may affect men's driving capability compared to women, but more research would need to be conducted to draw firm conclusions from this finding.

These results show that people who listen to their music at high levels may be affected cognitively while driving. It is important that drivers know the kind of effects that these high levels of audio may cause. Also, it is vital that when warning signals are being designed, they are designed carefully so that drivers do not underestimate their urgency, and so that warnings are not missed completely by the drivers. Alternatively, this could be accomplished with audio level limits for music outputs, or by muting the music output when a warning signal is being displayed.

Chapter 5: References

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Appendix: Music Selections for Up-Tempo and Down-Tempo Conditions

Song Title	Artist	Tempo
Ever The Same	Rob Thomas	Down
Say It's Possible	Jay Brannan	Down
The a Team	Ed Sheeran	Down
The Scientist	Coldplay	Down
Everything Has Changed	Taylor Swift	Down
Tell Me A Story	Phillip Phillips	Down
Over and Over	O.A.R.	Down
Come On Get Higher	Matt Nathanson	Down
So Easy	Phillip Phillips	Down
All We Are	Matt Nathanson	Down
I'm Not the Only One	Sam Smith	Down
Here	Alessia Cara	Down
Let It Go	James Bay	Down
Let Her Go	Passenger	Down
Jar of Hearts	Christina Perri	Down
White Horse	Taylor Swift	Down
Like I'm Gonna Lose You	Meghan Trainor	Down
Bad Blood	Taylor Swift	Up
The Great Escape	Boys Like Girls	Up
Roar	Katy Perry	Up
On Top Of The World	Imagine Dragons	Up
Shake It Off	Taylor Swift	Up

One Last Time	Ariana Grande	Up
Can’t Hold Us	Macklemore	Up
Anything Goes	Florida Georgia Line	Up
Heels Over Head	Boys Like Girls	Up
It’s Time	Imagine Dragons	Up
Break Free	Ariana Grande	Up
Hero/Heroine	Boys Like Girls	Up
Geronimo	Sheppard	Up
Stand By You	Rachel Platten	Up
Centuries	Fall Out Boy	Up
Single Ladies	Beyoncé	Up
Waka Waka	Shakira	Up