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Effects of sound types and volumes on simulated driving, vigilance tasks and heart rate

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Abstract. The objective was to determine whether specific types and volumes of sounds affect driving-related tasks. Participants completed six trials while exposed to different sound types (hard rock, classical music and industrial noise) and volumes (53 versus 95 db (A)). Participants executed a randomized order of tasks, involving: movement (MT), reaction time (RT), simulated driving (SimD), and non-conscious perception of masking stimuli. The results suggest high volumes impaired SimD, RT and MT. During hard rock music, accommodation HR was significantly higher whereas male RT was slower than female RT. However, RT was enhanced when subjects were exposed to hard rock music during a non-conscious task of longer duration. SimD crashes increased during quiet hard rock music in comparison to quiet industrial noise. Experimental HR was lower during quiet sound volumes for both genders. In summary, loud volumes affect simple vigilance whereas hard rock music may affect tasks involving concentration and attention especially with males.

Keywords: Noise, music, volume, non-conscious perception

1. Introduction

High levels of background noise can be a nuisance and affect human health [38,63]. The most obvious effect of high intensity noise exposure is noise-induced hearing loss [1]. Yet, noise also affects concentration [4,33,39] and human performance [58,65]. Button et al. [13] studied the effects of industrial noise and muscle contractions on simple and complex vigilance. High intensity industrial noise impaired reaction and movement times when responding to simple vigilant tasks and decreased performance during a complex vigilant task. It is not clear whether loud volumes of music, which may be considered as pleasant or arousing, may have similar detrimental effects on human performance?

From one perspective, music may facilitate activities that require high levels of attention and concentration [16,18,24,26,43] due to its stimulating nature. On the other hand, music may also be distracting to human performance during specific tasks [17,21,25,35]. Music (sound having rhythm, melody or harmony) may even be as distracting as noise (unwanted signal or disturbance) [27].

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It has been stated that approximately 91% of musical exposure occurs during automobile transits [56, 57], with rock music being the listened to most often [48]. However, the research has opposing opinions on whether music negatively impacts driving-related tasks.

One of the pioneer studies developed by Brown [10] studied the effects of background music, speech and silence during light and heavy traffic. Brown [10] reported that music might reduce stress during driving, lowering emotional arousal under frustrating circumstances, such as heavy congested traffic. It was summarized that listening to music may even have a slight beneficial effect on control activity of a vehicle [10]. However, the early studies found it difficult to distinguish whether background music demonstrated a positive or negative effect on driving performance [13,37].

More recent studies have highlighted both positive and negative outcomes in respect to driving performance and background music. In numerous instances, music facilitates performance during driving related tasks [5,43,50,59,64]. According to the literature, it seems that moderate or comfortable volumes of background music exposure improves one's performance when performing driving-related tasks. For example, Spinney [59] reported that quieter volumes of music played at 55 dB (A) provided an optimal driving condition in comparison to silence and loud music played at 85 dB (A). Moreover, drivers improve their awareness and performance when exposed to music that is in a range of their own subjective comfort level [64]. It was demonstrated that moderate levels of music intensities report the safest driving conditions in that it stimulates driver awareness [43].

Due to the stimulating nature of music, it may be purported that loud hard rock music may improve driving performance through enhanced reaction times and awareness [43]. However, the study conducted by Matthews and colleagues [43] only looked at loud volumes ranging between 70–90 dB (A), which may be lower than what is considered loud by today's younger driver. Thus, a moderate volume of music may in fact enhance driving performance, whereas loud volumes may distract drivers.

The literature has been somewhat inconsistent in reporting the findings on the effects background music has on driving related-tasks. Even though music has been shown to benefit driving performance and behavior, it still may be a major distraction and detrimental to driving abilities [5,47,55,59]. Additionally, high arousal music may deter driving performance due to competition for limited processing space within the cortex [47]. North and Hargreaves [47] found that high arousing music (low arousal: 80 bpm at 60 ± 5 dB (A); high arousal: 140 bpm at 80 ± 5 dB (A)), increased lap times and decreased performance during simulated driving. Thus, higher arousing levels of music may impair cognitive or driving related performance [47].

The purpose of the current study is to determine whether different types or intensities of music affect performance during driving-related activities. It is hypothesized that low volume sound will facilitate driving-related tasks, whereas loud volume sound will impair performance. In relation to type of sound, it is hypothesized that hard rock will affect tasks more detrimentally compared to classical music. Thus, the present study not only attempts to clarify the conflicting literature but also adds unique components such as the measurement of non-conscious perception reaction time.

2. Methodology

2.1. Participants

Six male (173 ± 6 cm, 72.57 ± 8.61 kg, 22 ± 1.21 years) and six female (171 ± 3.5 cm, 66.9 ± 15.1 kg, 27 ± 10.34 years) participants from the university community volunteered for the experiment. None of the participants indicated a history of hearing or visual impairments. All participants filled out Physical Activity Readiness Questionnaire (PAR-Q) form from the Canadian Society for Exercise Physiology to determine their general health status. If any health problems were reported they were excluded from the study. Additionally, all subjects held a valid driving license for at least four years. All participants indicated they either did not play or rarely played video games. Additionally, all subjects were initially unfamiliar with the steering wheel and video game used for the study. Participants read and signed a consent form prior to commencement of the study. The Memorial University of Newfoundland Human Investigations Committee granted approval.

2.2. Experimental design summary

Participants completed six different trials of 45 minutes each. Participants were subjected to a combination of auditory stimuli and sound intensities (volumes). Conditions for each individual included the same audio clips of loud (95 dB (A)) and quiet (53 dB (A)) levels of hard rock music, classical music, and industrial noise. Whereas hard rock music selections emphasized heavy bass (low frequency) components and classical was chosen for its greater treble (higher frequency) emphasis, industrial noise was composed of both very high and very low frequency sound. Conditions were randomized for all participants. Tasks performed during the testing block included: simulated driving performance (time to finish course, number of crashes and road shoulder hits), reaction and movement time tasks, and a non-conscious perception task. The dependent variables were dispersed randomly within the testing block. Prior to the experiment, participants were granted an orientation session in which they completed the experimental tasks without the conditions of music or noise.

2.3. Dependent variables

Dependent variables included reaction and movement time tasks, vigilance and driving performance (time to finish course, number of crashes and road shoulder hits), and heart rate (HR).

2.3.1. Vigilance tasks

Reaction time (RT) and movement time (MT) were measured with an apparatus developed by the Memorial University Technical Services (Electronics, Newfoundland, Canada). The testing apparatus consisted of an analogue timer (L15-365/099, Triton Electronics, Great Britain), a stop clock (58007, Lafayette Instrument Company, Lafayette, IN), a stop clock latch (58027, Lafayette Instrument Company, Lafayette, IN) which attached the analog timer and stop clock, a custom designed box (62 cm (length) $\times$ 15.5 cm (width) $\times$ 9 cm (height)) with the distance of 50 cm from centre of start button to the centre of the stop button, and a trigger plate for the start of the task [13]. The task required movement of the driving leg (right) following the illumination of an incandescent light bulb (Fig. 1). The subject began with the right driving foot on the start button. Once the light was illuminated, the participant would release the start button and move the right foot and leg to push the stop button. The time between the lighting of the bulb and the release of the start button was recorded as the RT. MT was measured as the duration between the illumination of the light stimulus and the pressing of the stop button. Three trials of RT and MT were randomly performed during a three-minute time period. All trials registered a MT & RT. The mean of the three trials were used in the statistical analysis of RT and MT.

2.3.2. Simulated driving (SimD) performance tasks

SimD performance was tested using a video game console (Playstation 2, Sony) with the software game, ‘Gran Turismo 4: The Real Driving Simulator’ (Sony Computer). The software permits the user

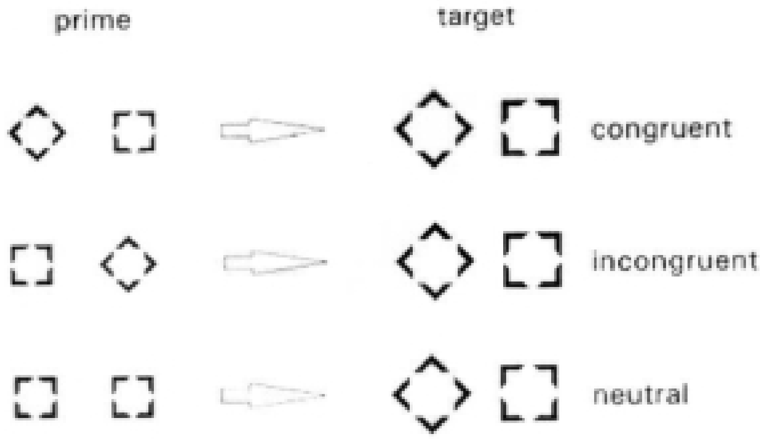

Fig. 1. Examples of Metacontrast Stimuli (Klotz & Neumann, 1999).

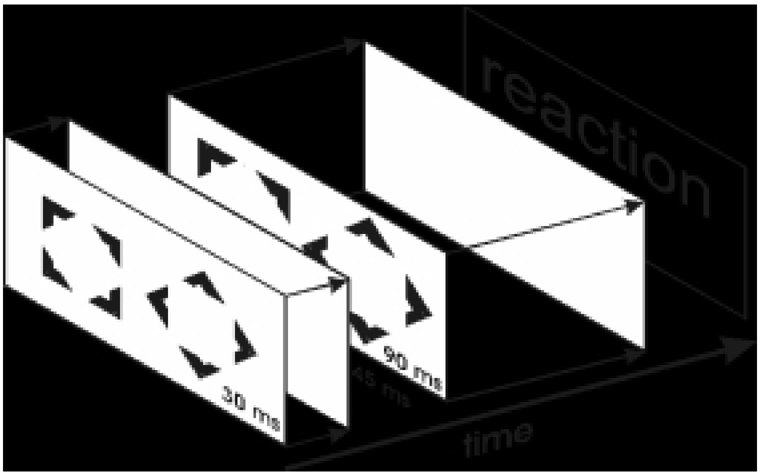

Fig. 2. Event Succession per Trial.

to complete individual timed laps. Lap times were recorded to the nearest hundredth of a second at the conclusion of a lap. Subjects controlled the game with the GT Driving Force Pro Force Feedback Racing Wheel (239298, Logitech) (see Fig. 2). The hardware (monitor and wheel) was secured to a desk with the monitor at head height and the wheel situated at mid-chest height. Accelerator and brake pads were placed under the desk in a similar position as found in North American cars. The same course and vehicle was used for each participant. Duration of the task was approximately five minutes. Driving performance measures included driving times, crashes, and shoulder hits. All participants were instructed that driving times, crashes, and shoulder hits were taken into consideration. All participants were granted a minimum 60-minute orientation session with the video game and its controls prior to the testing. In order to reduce any changes in driving times due to learning effects, subjects were permitted to practice with the video game console until a plateau of SimD time was demonstrated. This constituted a baseline for all participants.

2.3.3. Heart rate

HR was monitored with a heart rate monitor (Polar S810i Heart Rate Monitor, Polar Electro Oy, Finland, Model # 1903020). HR was recorded into three categories: resting, accommodation, and experimental. Resting HR was recorded approximately 5 minutes after the subject was seated and relaxing in the testing chair. Subjects followed the pre-fitness testing protocol associated with the Canadian Physical Activity and Fitness Lifestyle testing which includes abstention from food, caffeinated beverages and smoking for 2 hours, alcohol and exercise for 6 hours prior to testing. Testing was conducted at the same time of day to ensure consistency of diurnal rhythms. Accommodation HR was recorded approximately 2 minutes after the intended sound and volume commenced playback through the headphones placed on the subject. Experimental HR was recorded immediately following the termination of each testing variable in order to collect sufficient data points to represent an average heart rate over the 45 testing minute period. All heart rate measures are described in beats per minute (bpm).

Resting HR and accommodation HR were measured prior to the start of an experimental condition. HR was also measured during the experiment. All tasks were performed in the presence of music (hard rock or classical) or industrial noise.

2.3.4. Non-conscious perception

In research with healthy people, one experimental paradigm with which a direct specification of motor response parameters without conscious control has been successfully investigated is the Metacontrast Dissociation. It was first employed by Neumann and Klotz [46], based on earlier work by Neumann [45] and Wolff [66].

Participants performed a two-alternative choice RT task on a personal computer with geometric shapes as the stimuli. Participants were presented with a stimulus display that consisted of a target and a distractor. They were asked to execute one of two motor responses (e.g., pressing a left or right mouse button), depending on whether the target appeared on the left or right. Unknown to participants, these stimuli were preceded by a pair of masked primes, which were smaller replicas of the target (target-like prime) and/or of the distractor (distractor-like prime; Fig. 1). There were three conditions. In the neutral condition, the targets as well as the distractor were preceded by distractor-like primes. In the congruent condition, the target was preceded by a target-like prime, and the distractor was preceded by a distractor-like prime. In the incongruent condition, this mapping was reversed. Thus, to the degree that the masked primes cued a response, the correct response was cued in the congruent condition, and the incorrect response was cued in the incongruent condition, while no response was cued in the neutral condition.

The stimuli were presented on a 17” monitor (refresh rate 67 Hz), controlled by a microcomputer. Viewing distance was approximately 50 cm. Participants responded by pressing a mouse button. Stimuli were displayed in black (5 cd/m^2) on a white background (130 cd/m^2). A trial encompassed a dynamic fixation assistance, a prime pair and a target-distractor pair (Fig. 2). The target-distractor pair also served as a mask for the prime pair. The dynamic fixation assistance was employed to direct attention towards the center of the screen. Four dots moved from the corners to the center of the screen in 750 ms. At the starting position, the distance between the dots was 19 deg. In the center they merged into one dot and disappeared. The target-distractor pair was composed of a square and a diamond, each with star-like inner contours, aligned horizontally at a retinal eccentricity of 3 deg either above or below the center of the screen. The outer distance between the square and the diamond was 4.3 deg. The prime pair consisted of two smaller replicas of either two diamonds, two squares, a left diamond and a right square, or a left square and a right diamond. The outer contours of the primes coincided with the corresponding part of the inner contours of the target-distractor pair. Exposure durations were 30 ms (prime pair) and 90 ms (target-distractor pair). The stimulus onset asynchrony (SOA) was 75 ms.

The experiment took place in a dimly lit room and took about 15–20 minutes. In half of the trials the target-distractor pair was a left square and a right diamond, in the other half the arrangement was reversed. For half of the participants, the square was assigned as their target stimulus, for the other half the diamond was the target stimulus. There were three prime/target conditions. In the congruent condition the diamond in the target-distractor pair was preceded at its position by a diamond prime, and the square member of the target-distractor pair was preceded by a square prime. In the incongruent condition the assignment was reversed. In the neutral condition there were two identical primes that were smaller replicas of the distractors (squares or diamonds, depending on stimulus assignments). The inter trial interval was approximately 5–7 s. The experiment encompassed 180 trials in a random order, different for each participant and consisting of 60 each congruent, incongruent, and neutral prime/target pairings. A random generator arranged the order of the trials. In each of the conditions, there were equal numbers of trials with stimulus presentation above or below the fixation point, and with the target in the left or right position. These experimental trials were preceded by 10–15 practice trials. Participants were instructed to press the left mouse button with the index finger of their left hand if their assigned target appeared on the left, and the right mouse button with the index finger of their right hand if it appeared on the right. They were asked to respond as fast as possible, but try to avoid errors. If no response was registered within one second, RT was omitted. Response latency was measured from the onset of the target.

2.4. Independent variables

Each intervention (hard rock, classical, and industrial noise at loud and quiet volumes) was incorporated on separate occasions. Each session was performed within 24–48 hours of the previous session. All sessions per subject were tested at similar times during the day to account for circadian rhythms.

2.4.1. Auditory stimulus

Participants were subjected to digitally recorded (www.sounddogs.com) loud industrial noise volume (similar to construction and industrial work) of 95 dB (A) [54], quiet industrial noise volume (similar to a quiet office environment) of 53 dB (A) [49], loud hard rock music at 95 dB (A), quiet hard rock music at 53 dB (A), loud classical music at 95 dB (A), or quiet classical music at 53 dB (A). The hard rock music was a recording of various compilations (See Table 1 for song list). Meanwhile, a compilation of songs featuring the panpipes (Magic of the Panpipes, Gheorghe Zamfir, Universal Music, Willowdale, Ontario) was termed classical. While it is evident that panpipe music may not be considered in the same context as Bach or Beethoven classical music, the term classical will be used throughout this paper with the caveat that it may not be strictly considered classical. During both conditions, the music was randomly selected and played.

Subjects were exposed to each auditory stimulus through stereo headphones (HR-80, Toshiba, Japan) that were connected to am/fm stereo receiver (VRX-2700, Vector Research, USA). The National Institute for Occupational Safety and Health (NIOSH) advises that the average person can be safely exposed to auditory stimuli at 95 dB (A) for approximately one hour. The exposure during this experiment was approximately 45 minutes. To ensure auditory stimuli levels remained within NIOSH recommendations, auditory stimuli levels were averaged through a pre-test. A sound level meter (Sound Level Meter 33–2055, Radioshack, Canada) was placed between the headphones for a five-minute period prior to commencement of the experimental session in order to monitor the average decibel level.

Table 1
Hard rock music list

Black Sabbath – Iron Man (Warner Brothers, 1971)
Disturbed – The Game (Giant, 2000)
Hair of the Dog – Rise (Spitfire, 2000)
Megadeth – Disintegrators (EMI Music Canada, 1997)
Metallica – Frantic (Elektra Entertainment, 2003)
Metallica – Holier Than Thou (Elektra Entertainment, 1991)
Metallica – Sad But True (Elektra Entertainment, 1991)
Metallica – The Shortest Straw (Elektra Entertainment, 1988)
Mötley Crüe – Dr. Feelgood (Hip-O Records, 1989)
Motley Crüe – Kickstart my Heart (Hip-O Records, 1989)
Orgy – Blue Monday (Reprise, 1998)
Rammstein – Links 2 3 4 (Universal Music Group, 2001)
Rammstein – Zwitter (Universal Music Group, 2001)
Rob Zombie - Dead Girl Superstar (Universal Music Group, 2001)
Rob Zombie – Dragula (Universal Music Group, 1998)
Rob Zombie – Scum of the Earth (Universal Music Group, 2001)
Soil – The One (Sony Music Canada Inc., 2001)
White Zombie – Children of the Grave (Sony Music, 1994)

2.5. Statistical analysis

All data were analyzed with a three-way analysis of variance (ANOVA) ($3 \times 2 \times 2$) (type of sound, sound volume, and gender) with repeated measures (GB Stat V7.0 for Windows (Dynamic Microsystems, Inc.)) to determine whether there were significant main effects or interactions of the testing blocks. The non-conscious perception task was also analyzed with a three-way ANOVA ($3 \times 3 \times 2$) (meta-contrast condition, type of sound, sound volume) with repeated measures (GB Stat V7.0 for Windows (Dynamic Microsystems, Inc.)). F ratios were considered significant at $p < 0.05$. If significant main effects or interactions were present, a Bonferroni (Dunn's) procedure was conducted. Effect sizes (ES = mean change / standard deviation of the sample scores) were also calculated and reported [14]. Cohen applied qualitative descriptors for the effect sizes with ratios of 0.2, 0.5 and 0.8 indicating small, moderate and large changes respectively. Descriptive statistics include means $\pm$ standard deviation (SD) for both the text and figures.

3. Results

3.1. Simple vigilance tasks

3.1.1. Reaction time

Loud sound volumes (main effect for intensity) significantly ($p < 0.01$) impaired RT by 15% compared to quiet sound volumes (Table 2). Significant ($p < 0.01$) interactions were noted. Loud hard rock music, loud classical music and loud industrial noise impaired RT by 16.9%, 10.1% and 18.7% compared to quiet hard rock music, quiet classical music and quiet industrial noise respectively (Table 3). Loud classical music significantly ($p < 0.01$) decreased RT by 7.5% compared to loud industrial noise (Table 3). There were no significant differences between loud hard rock and loud classical music, nor loud hard rock music and loud industrial noise.

Males were more adversely affected by hard rock music compared to females. Hard rock significantly ($p < 0.01$, ES = 0.45: Medium) impaired male RT (0.314 s $\pm$ 0.06) by 9.5% compared to females (0.287 s $\pm$ 0.04). Other types of sound did not show any significant differences with respect to gender.

Table 2
Main Effects and Effect Sizes (ES) for 53 and 95 dB(A) (Mean $\pm$ SD)

	53 dB(A)	95 dB(A)
Reaction times $p < 0.01$, ES $= 1.01$ (Large)	0.282 ± 0.039	0.324 ± 0.042
Movement Time $p < 0.01$, ES $= 0.68$ (Medium)	512.1 ± 73.5	554.5 ± 62.7
Simulated Driving Times $p < 0.01$, ES $= 0.16$ (Small)	147.5 ± 11.4	149.5 ± 12.4
Experimental Heart Rate $p < 0.05$, ES $= 0.26$ (Small)	75.7 ± 10.8	79.1 ± 13.1

Table 3
Summary of reaction times during varying sound volumes and types (Mean $\pm$ SD). The following symbol (Φ) indicates that the values are significantly different from all other variables at 53 dB(A). An asterisk indicates significant differences between the two variables identified with the asterisk. Effect sizes (ES) describe the magnitude of change for the variables in that column

	Hard Rock	Classical	Industrial Noise
95 dB(A)	0.324 ± 0.040 s Φ	0.313 ± 0.038 s Φ, *	0.337 ± 0.048 s Φ, * *ES $= 0.5$: Moderate
53 dB(A)	0.278 ± 0.044 s ΦES $= 1.15$: Large	0.284 ± 0.038 s Φ ES $= 0.76$: Large	0.284 ± 0.037 s Φ ES $= 1.1$: Large

Table 4
Summary of SimD times in relation to sound volume and type (Mean $\pm$ SD). The following symbol (Φ) indicates that the classical music variable at 95dB(A) is significantly different from all other variables at 53 dB(A). The following symbol (Ω) indicates that the classical music variable at 53 dB(A) is significantly different from hard rock and industrial noise variables at 95 dB(A). The symbols (Ω, Φ) preceding the effect sizes (ES) describe the magnitude of change for the corresponding interactions

	Hard Rock	Classical	Industrial Noise
95 dB(A)	149.3 ± 13.2 s Ω Ω ES $= 0.19$: Small	150.12 ± 12.16 s Φ	148.9 ± 12.9 s Ω Ω ES $= 0.15$: Small
53 dB(A)	147.9 ± 11.1 s Φ ES $= 0.19$: Small	146.9 ± 12.1 s Ω, Φ ES $= 0.26$: Small	147.6 ± 12.1s Φ ES $= 0.21$: Small

3.1.2. Movement time

Loud sounds (main effect for intensity) significantly ($p < 0.01$) impaired MT by 8.2% compared to quiet sound volumes (Table 2). There were no significant interactions for MT.

3.2. Simulated driving (SimD) performance tasks

There was a main effect for gender with male SimD times (138.6 s $\pm$ 4.9) significantly ($p < 0.01$, ES $= 4.0$: Large) faster by 14.3% compared to female SimD times (158.4 s $\pm$ 7.8). A main effect for intensity illustrated that loud volumes of sound significantly ($p < 0.01$) impaired SimD times by 1.3% compared to quiet volumes of sound (Table 2). Significant ($p < 0.05$) interactions were noted. Loud classical music impaired SimD times by 2.1%, 1.7% and 1.5% compared to quiet volumes of classical music, industrial noise and hard rock respectively. Furthermore, quiet classical improved SimD times by 1.6% and 1.4% compared to loud volumes of hard rock and industrial noise respectively (Table 4).

SimD crashes showed a strong trend ($p = 0.056$) for hard rock music exposure to produce more crashes per lap driven by 18.4% (1.48 ± 1.16 to 1.25 ± 1.01 crashes per lap) compared to industrial noise (main effect for type of sound). In respect to gender main effects, sound type had no influence on male or female SimD crashes.

Table 5
Summary of SimD crashes per lap in relation to sound volume and type (Mean ± SD). An asterisk indicates significant differences between the two variables signified with the asterisk. Effect sizes (ES) describe the magnitude of change for the variables in that column

	Hard Rock	Classical	Industrial Noise
95 dB(A)	1.5 ± 1.30	1.25 ± 0.87	1.46 ± 0.89
53 dB(A)	1.4 ± 1.1*	1.5 ± 1.2*	1.1 ± 1.1
	ES = 0.4: Moderate	ES = 0.4: Moderate	

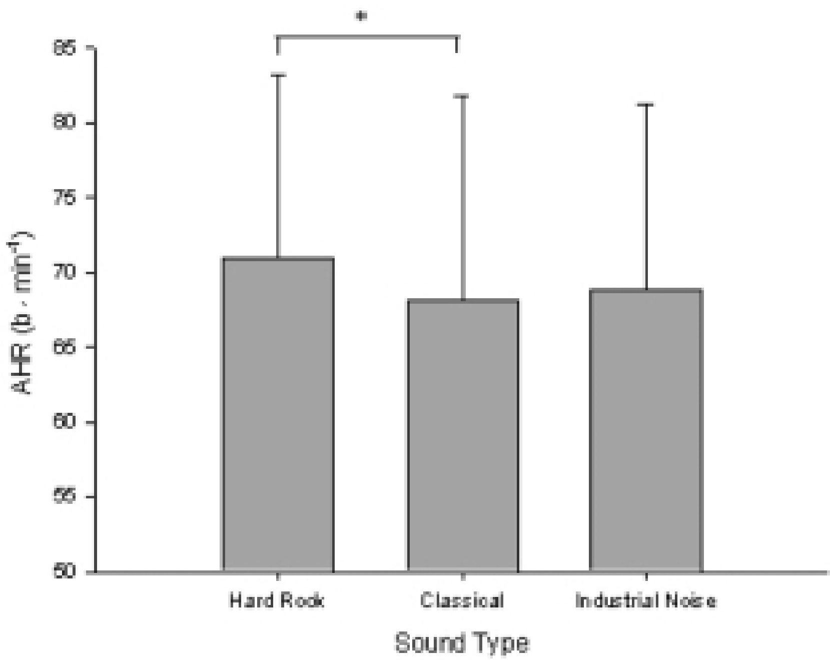

Fig. 3. Hard rock significantly ($p < 0.05$) increases accommodation HR. Asterisk indicates significant difference from the other variable indicated by the line. Values are means ± standard deviations (crossed lines).

When data were collapsed over gender, quiet levels of industrial noise significantly ($p < 0.01$) decreased SimD crashes by 40% and 44% compared to quiet volumes of hard rock and classical music respectively (Table 5).

There were no significant differences in respect to shoulder hits.

3.3. Heart rate

Male resting HR was significantly ($p < 0.01$, ES = 0.97: Large) lower (63 ± 9.2 to 72 ± 14.1 bpm) compared to females.

3.3.1. Accommodation heart rate

A main effect for gender was found with male subjects presenting significantly ($p < 0.01$, ES = 0.86: Large) lower accommodation HR by 12.4% (65 ± 9.2 to 73 ± 14.4 $\mathrm{b \cdot min^{-1}}$) compared to females. There was no main effect for volume. A main effect for type of sound indicated that accommodation HR significantly ($p < 0.05$, ES = 0.23: Small-Moderate) increased by 4.2% during exposure to hard

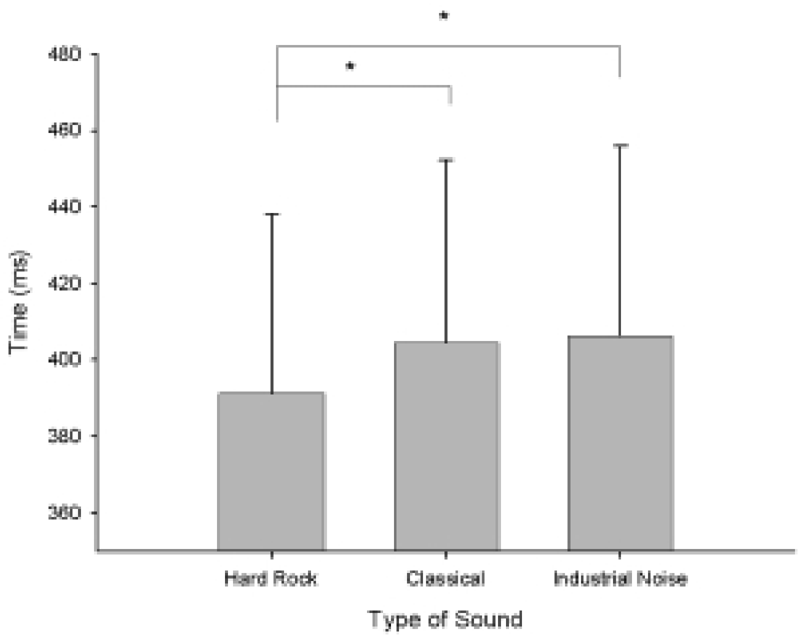

Fig. 4. Hard Rock music facilitated RT ($p < 0.01$). Asterisk indicates significant difference from the other variable indicated by the line. Values are means $\pm$ standard deviations (crossed lines).

rock compared to classical music (Fig. 3). Industrial noise showed no significant differences compared to hard rock or classical music.

3.3.2. Experimental heart rate

A main effect for gender was found with male HR (74 ± 7.8 b$\cdot$min^{-1}) during the experimental protocol being significantly ($p < 0.01$, ES = 0.89: Large) lower by 9.9% to compared to female HR (81 ± 14.3 b$\cdot$min^{-1}). A main effect for volume showed that experimental HR significantly ($p < 0.05$) increased during loud sound volumes by 4.5% compared to quiet intensity sounds (Table 2). There was no main effect for type of sound. An interactive effect showed that female experimental HR was significantly ($p < 0.05$, ES = 0.89: Large) higher during loud hard rock (85.9 ± 13.4) exposure by 16% compared to quiet hard rock music (73.9 ± 12.8).

3.4. Non-conscious perception: Metacontrast masking test

With data collapsed over type and volume of sound, RT was significantly ($p < 0.01$) different for all three conditions of the metacontrast masking protocol. Congruent RT was the fastest (372 ± 47 ms) followed by mixed RT (396 ± 38 ms), while incongruent RT were the slowest (434 ± 41 ms). Further, with data collapsed over sound volume and metacontrast condition (main effect for type of sound), hard rock music significantly ($p < 0.01$) facilitated RT of all metacontrast conditions by 3.3% and 3.8% compared to classical music (ES = 0.33: Moderate) and industrial noise (ES = 0.41: Moderate) respectively (Fig. 4).

4. Discussion

Similar to previous research [13] the present study illustrated that high volume sounds significantly impaired RT and MT. In the current study, high volume sound impeded SimD time performance. Unique to the present study, male RT was adversely affected by hard rock music. Conversely, hard rock music generally (high and low volumes) improved RT during a metacontrast-masking task.

4.1. Sound and simple vigilance performance

Data from the current study indicated that high volume sounds of any type (hard rock, classical, or industrial noise) impaired RT and MT tasks significantly. These findings confirm previous studies in the area of high volume noise and music on vigilant activity [5,13,64]. These results have been noted previously in the literature where music is as distracting as noise during human performance [27].

In a similar vein, it is well documented that cell phone use impairs driving performance [2,11,51]. Cell phone utilization during crucial driving maneuvers erodes performance, decreases overall safety margin, and distracts drivers from critical primary tasks [31]. Talking on a mobile phone impairs reaction time to a braking stimulus [15], increases crash risk [34], and distracts drivers from performing critical maneuvers [31]. Furthermore, delayed reaction times during driving increase the severity of the impact upon collision and it is enhanced at highway speeds [12,41]. The effect of cell phone use may be more critical than just listening to loud volumes of noise or music since it is considered dual-task processing [60,61]. Thus, it not only involves listening but conversing as well. The act of conversation interferes with reaction time. According to Consiglio and others [15] conversation performed either in person or by telephone caused slower reaction times. Additionally, conversation limits one's functional field of view while driving [3].

But why would loud volumes be detrimental to performance? It was purported recently by Button and colleagues [13] that loud volumes may impact vigilance due to its greater processing demands on the central nervous system (CNS). Attention may be deterred from the task at hand; thus, causing an impaired RT and MT. Another reason is that such high volumes of sound may cause an anxiety effect within the subjects [20]. It is well documented that chronic exposure to noise increases stress levels [22, 23]. According to Hébert et al. [32], auditory input in the form of background music significantly increased stress response during video game play. Increased anxiety level response is also supported by the present study in which experimental HR was significantly increased during exposure to loud sounds. Increasing the state of anxiety and stress seems to over arouse the CNS, which in turn deters performance. Delay and Mathey [19] discovered that subject's performance during a time estimation task increased consistently between noise intensity levels of 50 to 80 dB (A). Nevertheless, as the noise intensity approached 90 dB (A) the subject's ability to estimate time decreased [19]. Accordingly in the present study, simple vigilance was impaired perhaps as a result of higher levels of arousal impacting anxiety and processing within the CNS. Based on this study and the previous study from our laboratory [13], any form of loud sound whether it be an irritating noise or preferred music will have a negative impact on simple vigilance tasks which could include activities such as the time it takes to apply the brakes or adjust the steering wheel while operating a moving vehicle.

Possibly originating from similar mechanisms, loud classical music was significantly more detrimental for RT compared to loud industrial noise. Due to the nature of classical music, the auditory stimulus is complex in design and may have greater arousal and higher processing demands compared to simple random noise. There may be an increased attentional demand for this type of music in comparison to loud industrial noise. According to North and Hargreaves [47] higher arousing music led to worse performance during a SimD activity. It was proposed that the results reflect the possibility that the concurrent music and task compete for limited cognitive space. Also, an important note to mention is that RT was affected to a greater extent than MT. This result replicates the findings of Turner and associates [64]. They suggested that RT might be a more crucial factor in response time during visual vigilance performance. The finding that loud classical music induced greater impairment than industrial noise is a unique finding. It should be recognized that loud sounds whether deemed enjoyable or not can adversely affect performance.

Male participants were more adversely affected by hard rock music in comparison to females during simple vigilant performance. One common thread prominent in hard rock music utilized for this study and popular today is the abundance of bass. The preference for this type of music may be affected by many variables, including gender, individuality, or psychoticism [44]. As reported by McCown and colleagues [44], males prefer music containing additional bass. In a survey study conducted by McCown [44], 73 of 85 vehicles with enhanced speakers to reproduce exaggerated bass sounds were driven by males. Hence, similar to the distracting effect of loud noise for both genders, the bass-induced arousal in males would interfere with the cognitive processing associated with simple vigilance [47]. However, non-conscious perception RT did not show similar results in the present study.

4.2. Non-conscious masking performance and sound type

Whereas, conscious recognition and reaction to stimuli are obviously important to movement performances such as driving, the non-conscious perception of stimuli also contributes to the successful execution of rapid tasks. Similar to previous research [36,46], the current study revealed metacontrast dissociation, which signifies non-conscious perception. However, RT did not show any significant differences to the level of sound volume during the metacontrast-masking test even though the simple vigilance task reported detrimental effects to loud volumes. One postulation could be that the stimuli for this non-conscious task are more centrally processed as opposed to the simple vigilance task. The simple vigilance task encompasses peripheral field of vision as well. It has been reported in the literature that loud volumes distract response time to peripheral stimuli, but not centrally located stimuli [5]. It was demonstrated by Beh and Hirst [5] that participant's response times were facilitated by exposure to both quiet and loud music conditions. However, high volume music impaired response times to peripheral signals. Thus, the intensity of the music may not have an effect during the non-conscious perception task due to the centrally located stimuli.

Another possible postulation is that visual stimuli are processed via varying pathways within the CNS, which is known as the two-system theory [29]. According to Goodale and Humphrey [30] there may be a separation in processing visual stimuli via the dorsal pathway or the ventral pathway. The non-conscious may be more centrally processed via the dorsal pathway; whereas the simple vigilance stimuli may have been processed via the ventral pathway [29]. Therefore, the different processing routes of the visual stimuli may be a factor as to why loud volume sounds have a greater affect on the simple vigilant task.

Another interesting finding in the current study was the observation that hard rock music improved RT when data were collapsed over volume of sound and metacontrast condition. In previous studies, hard rock music has been shown to facilitate simple performance [43,59,64]. According to Turner and colleagues [64], the arousing and stimulating nature of hard rock music may enhance speed of reaction to particular stimuli.

4.3. Sound and simulated driving (SimD)

In the present study, loud sound volumes significantly increased SimD times per lap. According to Spinney [59], rock music played at moderate intensities (55 dB (A)) facilitated driving performance and may provide for optimal driving conditions; whereas, loud intensities (85 dB (A)) of rock music are detrimental to driving performance. Due to the distracting effect of loud sound volumes during SimD, the participants of the current study were unable to match the lap times of the lower sound volumes. As previously stated, the louder volumes seem to require greater cognitive processing within the CNS.

There were no significant differences in the volume of sound on SimD crashes, yet, the type and intensity of sound in the current study affected SimD crashes. Quiet volumes of hard rock and classical music increased the number of crashes in comparison to quiet industrial noise. During the quiet intensities, the level of sound is at an approximate equivalent to a quiet office space [49]. During quiet industrial noise exposure there was little requirement for central processing. However, during exposure to quiet volumes of hard rock and classical music the lyrics of the music were heard as a whisper. Therefore, CNS processing may have increased to more fully appreciate the music being played. Furthermore, Turner and colleagues [64] reported that lower and higher music volumes (60 dB (A) and 80 dB (A)) were detrimental to driving performance, whereas a moderate level of intensity was determined optimal.

The current study reported that males on average had faster SimD times than females. According to previous research [52,53] males are superior to females in terms of visuomotor and visuospatial attention skills. Therefore, females may have shown greater caution during the SimD task.

5. Heart rate and sound

During both recordings of experimental and accommodation HR, male HR was significantly lower than female HR. However, this may be simply due to the population tested. Prior to the testing, the resting HR was recorded and male HR was lower during this measure as well.

Further data analysis demonstrated that accommodation HR increased during exposure to hard rock music. Random noise has also been shown to increase HR [22]. Whereas a 4.2% increase in heart rate might not be considered to be substantial, it can be an indication of the increased effect of sound on the sympathetic system [23]. It is known that rhythms of the respiratory system and heart closely resemble that of musical beats [7]. Auditory inputs have been shown to produce entrainment in respiratory timing and thus, music may be able to modify breathing frequency [40,62]. With entrainment activating an arousing response [62], the music-induced increase in HR may depend upon the amplitude, tempo and rhythm of the input [5–7,9]. Hence, the high tempo hard rock music influenced the accommodation HR in this study.

The current study also reported that experimental HR increased during exposure to high volume sounds. Previous research has demonstrated that loud noise may increase irritability and stress, such as heart rate and blood pressure due to the increased sympathetic response [22,42]. Further, research has discovered that loud sounds, either chronic or acute may increase stress, as well as cardiovascular measures [8,23,28]. Thus, similar to previous studies, the high volume sound increased HR during the experimental sessions.

6. Conclusions

The current study demonstrated that intensity and type of sound could have detrimental effects on driving-related tasks. High volume sounds decrease simple vigilance and SimD performance tasks.

Similar to loud noise levels, these decrements may be a result of greater arousal and stress levels, associated with greater processing within the CNS. Further, high volume sounds may also be distracting, thus taking away from concentration and attention needed for driving performance.

7. Research implications

Listening to loud volumes of popular music is a trendy ritual during today's automobile transits. However, this act may affect concurrent tasks involved in automobile control due to detrimental effects on RT and MT. When driving at 100 km/hr, an approximate 20% decrease in RT and 10% increase in MT would result in the car coming to stop 2–3 metres farther than when not subjected to loud volumes. Although, 2–3 metres may not a first glance seem substantial, it could certainly be catastrophic to the pedestrian who inadvertently and suddenly walks in front of your moving vehicle.

More so, the popular choice of music to escort today's male drivers is hard rock. Yet males are most susceptible to its detrimental effects. Hard rock music impairs male RT more so than females. From one perspective, hard rock music may seem to be an excellent choice due to its facilitation response during centrally located stimuli. However, there are other decrements that may outweigh this benefit. The present study reported hard rock music increased SimD crashes, which may lead to speculation that attention is decreased during this type of auditory stimuli. Therefore, not only does the volume level of music one listens to, but also the type of music one listens to may magnify driving capabilities related to attention and concentration. However, one limitation to the current study was the varying tempos of the background conditions. Yet, it is still safe to state that the listening amplitude and type of musical selection should be taken into consideration before venturing onto the busy roadways.

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