



The effects of music tempo on simulated driving performance and vehicular control

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Abstract

The automobile is currently the most popular and frequently reported location for listening to music. Yet, not much is known about the effects of music on driving performance, and only a handful of studies report that music-evoked arousal generated by loudness decreases automotive performance. Nevertheless, music tempo increases driving risks by competing for attentional space; the greater number of temporal events which must be processed, and the frequency of temporal changes which require larger memory storage, distract operations and optimal driving capacities. The current study explored the effects of music tempo on PC-controlled simulated driving. It was hypothesized that simulated driving while listening to fast-paced music would increase heart rate (HR), decrease simulated lap time, and increase virtual traffic violations. The study found that music tempo consistently affected both simulated driving speed and perceived speed estimates: as the tempo of background music increased, so too did simulated driving speed and speed estimate. Further, the tempo of background music consistently affected the frequency of virtual traffic violations: disregarded red traffic-lights (RLs), lane crossings (LNs), and collisions (ACs) were most frequent with fast-paced music. The number of music-related automobile accidents and fatalities is not a known statistic. Police investigators, drivers, and traffic researchers themselves are not mindful of the risks associated with listening to music while driving. Implications of the study point to a need for drivers' education courses to raise public awareness about the effects of music during driving. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Simulated driving; Music effects; Vehicular music; Music tempo; Driving performance; Control; Speed estimates

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1. Introduction

1.1. Vehicular music listening

The use of music in everyday life has finally been taken to the center stage of music science research. Until now, few studies have documented how real people employ music in particular social spaces or temporal settings. But recently, several studies have capitalized on a conceptual underpinning whereby the effects of music are not disassociated from the specific contexts of use; these point to the fact that not only do we do things to music, but most of the time we do things with music. DeNora's ethnographic study exploring how music is used in Western culture confirms that we ride, eat, fall asleep, dance, romance, daydream, exercise, celebrate, protest, purchase, worship, meditate, and procreate – with music playing in the background (cf. DeNora, 2000).

To investigate everyday involvement with music, Sloboda cued the responses of 500 representative correspondents of the 1998 Sussex Mass Observation survey (Sheridan, 2000) with questions such as: 'Do you use music in different ways?' and, 'Are they (i.e., the music pieces) linked to particular times, places, activities, or moods?' The findings demonstrate that activities which were accompanied by music were predominantly domestic or solitary, and most frequently included housework or driving (Sloboda, 1999). In a follow-up study investigating specific functions of music in everyday life, (Sloboda, O'Neill, & Ivaldi, 2000, 2001) studied diary-type journals of non-musician participants whereby entries were written subsequent to hearing a random pager signal 7-times per day for one week. The whereabouts of the participants most often recorded in the journals was their home (50%) and workplace (21%), while transit (10%), and commercial outlets/entertainment venues (6%) were also reported but to a lesser extent. Nevertheless, the frequency to which music was experienced during episodes was significantly contrary: transportation (91%), commercial outlets/entertainment venues (86%), home (46%), and workplace (5%). The study demonstrates that while many situations involving everyday activities offer little room for music involvement, other types of activities are more open to such stimuli. Accordingly, music exposure is more likely to occur when the person is alone in situations associated with the opportunity for personal choice over the music (Sloboda, 1999; Sloboda et al., 2000, 2001).

It is somewhat absurd that the popular location where individuals seem to be found when they listen to music is not in the comfort of their living room, nor is it shared with social agents such as intimate partners, extended family, or friends. Rather, the circumstance most frequently reported while listening to music involves unaccompanied vehicular driving. It should not, then, be surprising that many automobile consumers outfit their vehicle as an audio-environment. Over the past decade, the once-upon-a-time standard AM/FM car-radio receiver has been replaced with the radio/tape-cassette player as a stock-item. Today, many drivers further customize their automobile with audio-components including compact-disk players, changers, amplifiers, equalizers, and speakers of various configurations and frequency ranges. This consumer behavior sparked-off several studies (Melka & Pelent, 1999; Ramsey & Simmons, 1993) which measured owner-adjusted acoustic outputs of car stereo systems, and evaluated the overall sound quality of various cabin-positioned loudspeaker installations. These studies highlight the subjectivity for acoustical and psychological peculiarities of listening to reproduced music in car interiors. Clearly, the future

trends for 'audiophile-drivers' will involve customizing their vehicles with PC-interfacing downloadable MP3-players.

The relationship between music, driver, and the automobile was studied by Oblad (2000) who presumed that more than just an attraction, individuals have specific expectations when they play music in the car. She felt that it is not necessarily the music drivers want to listen to, but rather, they simply want to spend time in the car with accompanying music. Oblad reported that the music played most often in the car was rhythmic, vocal, and familiar popular hit songs or varieties of 'rock' music. She claimed that many drivers were aware of their own reactions to specific melodies, and chose music pieces differentially. Accordingly, participants described the effects of music as influencing both their rhythms of driving and concentration, as well as changing their perceptions of relaxation and stimulation. Drivers reported to feel 'near' or 'inside' the music, and perceived the experience as 'impenetrable'. Oblad postulated the existence of an interactive co-dependent relationship between driving and music, which was conceived early in one's driving history during the mid-late teen-years. It is interesting to note that previous studies (Arnett, 1991, 1992; Gregersen & Berg, 1994) pointed to an inter-relationship between music and driving, but these directly associated specific music with negative lifestyle, driving recklessness, and traffic accidents; 'heavy-metal' and 'hard-rock' music correlated with significantly higher rates of driving while intoxicated, accelerated driving speeds, and traffic accidents among adolescents and young novice drivers. Finally, exploring the impact of music on driving performance, Oblad employed a car designed by the Swedish Road and Transport Research Institute to monitor spontaneous verbal commentaries, as well as on-the-road performance parameters including clutch, brake, and accelerator pedals. Oblad reported that accelerated driving speeds occurred as a result of the music being played in the car. She noted that when a driver liked the music, the sound level could never be high enough, and intensity level always caused accelerated cruising speeds.

1.2. Effects of intensity on vehicular control

In a recent review (Staum & Brotons, 2000) five music-listening environments differentiated by their intensity levels (dBA) were identified: comfortable listening (± 70 dBA); symphony concert (76–100 dBA); Walkman headphone (± 90 dBA); bar and dance-club (± 100 dBA); and amplified rock concert (> 112 dBA). It is of particular interest, then, that Ramsey and Simmons (1993) previously measured in-car driver-adjusted acoustic outputs in the 83–130 dBA range. One must question if aural stimuli presented at intensity levels as these impede on driving performance (and therefore place the driver at increased risk), or facilitate driving performance (and hence reduce actual everyday hazards). For example, a most interesting study by Ayres and Hughes (1986) demonstrated that different types of aural stimuli presented at the same level of intensity do not necessarily encode the same acoustic characteristics, nor cause the same level of effects. The study found that while visual search and pursuit tracking tasks were unaffected, visual acuity was impaired when loud background music (107 dBA) was presented (but no effects were seen for music at 70 dBA nor for either noise at 70 dBA or noise at 107 dBA). This finding suggests that momentary peak levels in loud-music may play a role in disrupting vestibulo-ocular control. Clearly while not all auditory stimuli interfere with visual tasks, music is somewhat different than other forms of aural stimuli (for example, noise and verbal instructions) in that it is more prone to cause

temporary havoc with performing primary tasks (and it may even increase demands exceeding dual-task processing capacity).

In actuality, some people feel that driving with music in the background is itself the cause of automobile catastrophes. Spinney (1997) challenged such speculations demonstrating that music exposure during driving actually increased performance ability with improved reaction times; accordingly, background music facilitates avoidance of driving hazards. Turner, Fernandez, and Nelson (1996) also found a significant decrease in response time to randomly presented unexpected red lights (representing automobile rear break-lights) with music at 70 dBA (but not for either music at 60 dBA or music at 80 dBA). Nevertheless, most people believe that soft music facilitates driving (or at least does not affect the cognitive aspects of the performance), while loud music impairs vehicular control. This belief may be perpetuated as driving is seen as a complex task involving a vigilance component. Hence, certain aspects of driving are expected to improve with low-to-moderate intensity background music. With this in mind, Beh and Hirst (1999) explored low-demand single-task driving versus high-demand multi-task driving under soft (55 dBA) and loud (85 dBA) background music conditions. The results indicated that while the simple tracking tasks were not affected by either music intensity, and that response times to centrally located visual signals (i.e., shorter stopping times to critical signals in the driving environment) improved with both music intensities, louder music significantly increased reaction times to peripheral signals during high-demand driving. These findings demonstrate that while there may be beneficial effects of softer music on vigilance, the improvement in response time to central signals for louder music was off-set by an increase in response time to peripherally located cues. This, then, suggests an interaction between music intensity and attentional focus, whereby lower intensity music facilitates performance requiring a broad attention span, yet higher intensity music impairs performance under such conditions. Beh and Hirst conclude that while it could be argued that louder music may be a benefit to driving performance under increased attentional demand for signals located within central vision, the trade-off of an increase in response time to peripheral signals essentially nullifies any advantage.

On face value, it might appear that music's effects are solely attributable to 'intensity' or loudness. For example, North and Hargreaves (1997) concluded that drivers tend to turn down the radio volume in heavy traffic as loud arousing music requires greater processing demands. Nevertheless, it seems appurtenant to question the variance of music intensity on driving. Especially when considering that some music genres are composed of highly dense and active musical characteristics, how loud they are played might not actually have any bearing whatsoever on vehicular control. Hence, North and Hargreaves (1999b) explored the effects of music 'complexity' on driving performance. The basis of their study was the following: (1) listening to a piece of music requires cognitive work (such as, analyses of musical components, and on-line temporal processing of fluid auditory combinations); (2) arousing music (which is more cognitively-demanding) will reduce the amount of attentional space available; and (3) when arousing music and driving draw simultaneously on the same limited processing capacity driving performance will be significantly impaired. The study utilized a PC-controlled simulated 5-lap motor-race course. Low-demand and high-demand simulated driving tasks were accompanied by either moderately-slow/soft 'low-arousal' music (80 bpm at 60 dBA) or fast/moderately loud 'high-arousal' music (140 bpm at 80 dBA); a measure indicating the number of beats per minute is referred to as 'bpm'. The results indicated interaction effects between task difficulty and music type: simulated speed-

driving was best performed in the low-demand/low arousal music combination. While these results provide valuable information, the researchers' claim to have examined 'music complexity' appears unlikely. Music theorists view complexity as the resultant perception borne-out from the confederation of effects and interactions of several stimulus properties, and not as autonomous element. It would then seem imprudent to assume that it could be teased-out in such a discernible fashion. Yet, when considering their stimuli (i.e., 80 bpm at 60 dBA versus 140 bpm at 80 dBA), it might be warranted to view the study as an exploration of the combined effects of 'tempo + intensity' on simulated speed driving.

1.3. Effects of tempo on vehicular control

In the context of everyday environments, background music variegated by tempo have been seen to modify human motor-behavior. Studies demonstrate that supermarket shoppers move around the store more quickly with fast-paced music than with slow-paced music, restaurant patrons eat their meals more quickly in the presence of fast- rather than slow-tempo music, and drinks in pubs are consumed more quickly and aggrandize to the gradually increasing tempo of music heard in the background (Herrington & Capella, 1996; North & Hargreaves, 1999a; North, Hargreaves, & Heath, 1998). Traditionally, studies exploring the effects of music tempo investigate both the speed and accuracy of human task performance. For example, fast music increases the rate and precision of mathematical computations in stock-market environments (Mayfield & Moss, 1989), step-up self-paced line drawings (Nittono, Tsuda, Akai, & Nakajima, 2000), and accelerate driving speeds (Konz & McDougal, 1968). Moreover, several studies note that music tempo also affects aspects of human perceptual processing. Iwamiya and Sugimoto (1996) and Iwamiya (1997) reported that drivers characterized scenic country sides as either 'pleasant' (with slow-tempo background music) or 'powerful' (with fast-paced background music) even though identical video-clips of panned landscapes were viewed.

However, the most outstanding music effect of particular relevance to driving performance is that related to time perception – especially when considering how perception of 'time' overlaps with the perception of 'velocity'. In contexts where the visual field is more or less stationary, music has been seen to affect time judgments. For example, shoppers incorrectly perceived that they spent more time shopping when they heard familiar background music (Yalch & Spangenberg, 2000), and patients incorrectly perceived that they spent less time waiting in reception halls when listening to music (North & Hargreaves, 1999a). These inconsistencies relate to the fact that music itself is a temporal stimulus, and that sensory input of a temporal nature perhaps interferes with other temporal perceptual impressions (such as internal timing mechanisms). North et al. (1998) point out that music preference also influences how 'time' is perceived (as less information is encoded when music is disliked), and that higher intensity levels lead to longer time-estimates (as more salient features evoke higher levels of attention, processing, and recall).

Nonetheless, in contexts where the visual field is a constantly changing stream – such as during vehicular driving – the effects of music may be far more complex. Levin and Zakay (1989) demonstrated that time perception relates to the number of events processed within a given period, and increases with both the amount of memory taken up by an event as well as with the number of changes that occur during a specific period. Hence, even when both faster and slower

moving objects start and stop together, faster moving objects are perceived as traveling for a longer period of time (Zakay, 1989). Conceptual links between ‘time’, ‘velocity’ and ‘distance’ – based on experiences that faster moving objects travel a greater distance during a fixed time interval than slower moving objects – is formulated at an early developmental stage. Therefore, already in childhood we equate ‘quicker’ with ‘longer duration’. By the same logic, it could be hypothesized that musical stimuli which move at higher levels of perceived activity (i.e., at a faster velocity, pace, or tempo) will be perceived as longer in duration than musical stimuli which move at lower levels of perceived activity. To test such a presumption, North et al. (1998) investigated the effects of slow (< 80 bpm) versus fast (> 120 bpm) pop tunes on the perceived time spent on fitness training. The study demonstrated that time spent in a gym was under-estimated, and that time estimates were less inaccurate with fast-paced music. The researchers concluded that time was experienced to some extent in terms of the subjective pace of the accompanying background music. They tie these findings to Zakay’s conceptual model accounting for effects of incongruent temporal information as distorting attention from internal cognitive timers, and further purport that the greater degree of time-inaccuracy (with slow music) was attributable to ‘music-situation incongruence’.

1.4. Study aims and hypothesis

No study as yet has investigated the role of background music tempo on driving performance (especially while controlling for intensity). The current study was therefore planned to explore the effects of this music stimulus parameter utilizing several dependent measures (such as cardiovascular activity, simulated driving acceleration, and virtual traffic violations). It was hypothesized that PC-controlled simulated driving with fast-paced background music (>120 bpm at ± 85 dBA) will significantly increase heart rate (indicating higher levels of physiological arousal), decrease simulated lap-time (indicating accelerated speeds), and increase the amount of virtual traffic violations (indicating reckless behaviors), in comparison to simulated driving with no-music, slow-paced music, or medium-paced music. Furthermore, the extent to which the tempo of music heard during vehicular driving contributes to information processing failures has also not as yet been considered; therefore, the study investigated possible interference effects of music tempo on perceived speed-estimates. The presumption about music-situation incongruence highlights a significantly overlooked line of research in the context of music effects on driving performance and vehicular control. This focus is especially warranted when considering the associated link between ‘time’ (duration) and ‘speed’ (velocity) in temporal events such as driving. While the study exclusively highlights PC-controlled simulated driving, it is clear that on-the-road inaccuracies involving perception of velocity could have serious implications.

2. Experiment 1

2.1. Participants

Twenty ($N = 20$) music education students participated in the study for course credit. On average they were 32.6 years old (S.D. = 7.2285), with a majority (70%) being women (a gender-

bias attributed to more female students enrolled in music education). The participants had passenger-car licenses for an average 11.4 years (S.D. = 5.3860), and nearly all (95%) reported to have had no previous traffic-related judicial action taken against them. It should be pointed out that self-report driving behavior has been reported as highly reliable (West, French, Kemp, & Elander, 1993). All of the participants reported that they listen to music while driving: 65% reported that they drive with music ‘all of the time’, and 30% reported that they drive with music ‘most of the time’. The majority (87%) reported that they listen to moderate-tempo (85–110 bpm) music, at medium-intensity (50–60 dBA) sound levels.

2.2. *Stimuli*

In order not to contaminate the music stimuli with extra-musical associations and surface cues (such as those related to popularity, language, ethnic origin, gender, sensuality, and sexual preference), the music stimuli did not include vocal performances involving lyrics, nor instrumental cover-versions of well-known popular tunes. Only neutral sounding instrumental pieces were considered. All prospective stimuli characterized a fusion music incorporating pop, rock, jazz, blues, funk, and country genres. The typical orchestration was composed of a rhythm section (drums, bass guitar, electric guitar, and electronic keyboard) and a solo instrument (electric guitar, electronic keyboard, or woodwind/brass instrument); in some pieces a backing strings-section was present for added texture or mood painting. Prospective selections were classified as either slow-tempo (40–70 bpm), medium-tempo (85–110 bpm), or fast-tempo (120–140 bpm). All audio-tracks were subjected to tempo criterion ratings by three independent referees (16, 25, and 43 years old), who used a Swiss-made analog Cadenzia Pocket Metronome (Neuchatel) to measure the felt pulsation of the main beat of each track. Selections that deviated between the judges by more than 10% were dropped from the stimuli pool. The final selection of music used in the study consisted of twelve tracks (four for each of the three music tempos). See Table 1.

2.3. *Apparatus*

Simulated driving was controlled by a Dynasty (Mitsuba) 3D Multi-Media Notebook computer (Intel 233 MMX lap-top computer, 12.1" TFT SVGA LCD display, on-board 16-bit digital stereo sound Yamaha audio system), with external AC/powered full-range (20–20 kHz) PC Stereo Speakers (Mli 691H at 7 w), and a Side-Winder Force Feedback Steering Wheel with Pedals (Microsoft). Simulated driving was executed with ‘Mid-Town Madness’ (Chicago Edition) software (Microsoft), performed in single-user cruise mode. Music stimuli (CDs) were presented via a 24 w micro-component stereo (JVC UX-T150) with two detachable wooden-cabinet stereo speakers placed on the floor at 45° angles (upwards) facing the subject. Loudness was monitored and controlled (± 85 dBA) with a digital sound level meter (Radio Shack #33-2055; accuracy ± 2 db; range 50–126 db SPL). Physiologic arousal was measured continuously, recorded and stored every 15 s, with a wireless Polar Accurex-Plus™ Heart rate monitor (Polar

Table 1
Music stimuli used in the study

#	Tempo	Track title	Artist	Album source	BPM	Exposure
1	Slow	Stranger On The Shore	Kenny G	Classics In The Key Of G (1999, Arista/BMG) 07822-19085-2; LC 03484	56	2:50
2	Slow	Being With You	George Benson	Best Of George Benson: The Instrumentals (1997, Warner Bros.) 9362-46660-2; LC 0392	65	3:54
3	Slow	Like A Lover	Earl Klugh	Late Night Guitar (1999, Blue Note/Capitol) 7243-4-98573-2-2; LC 0133	63	2:40
4	Slow	Heart To Heart	Larry Carlton	Larry Carlton Collection, Volume 2 (1997, GRP/BMG) 11105-98892-6; LC 6713	66	4:23
5	Medium	That's Right	George Benson	Best Of George Benson: The Instrumentals (1997, Warner Bros.) 9362-46660-2; LC 0392	94	4:58
6	Medium	Cashaca	Spyro Gyra	Spyro Gyra 1977–1987 (1997, BMG/RCA) 74321-47123-2; LC 0316	112	4:18
7	Medium	Dinorah Dinorah	George Benson	Best Of George Benson: The Instrumentals (1997, Warner Bros.) 9362-46660-2; LC 0392	112	3:41
8	Medium	Cafe Amore	Spyro Gyra	Spyro Gyra 1977–1987 (1997, BMG/RCA) 74321-47123-2; LC 0316	100	5:02
9	Fast	House Trip	DJ Jurgen (DJ Paul One VS Dave Scott)	This Is DJ Jurgen His Favorite Tracks Part 2 (Star Traxx, The Hague) F7056 STA-99001	132	4:30
10	Fast	Angels	DJ Jurgen (Sequential One)	This Is DJ Jurgen His Favorite Tracks Part 2 (Star Traxx, The Hague) F7056 STA-99001	132	3:30
11	Fast	Kiss That Sound	DJ Jurgen (Pulsedriver IV)	This Is DJ Jurgen His Favorite Tracks Part 2 (Star Traxx, The Hague) F7056 STA-99001	132	2:40
12	Fast	The Was It Isn't	DJ Jurgen (Horney Bruce)	This Is DJ Jurgen His Favorite Tracks Part 2 (Star Traxx, The Hague) F7056 STA-99001	132	5:20

Electro Oy; accuracy $\pm 1\%$ or ± 1 bpm).¹ The HR monitor consists of an integrated light-weight one-piece coded transmitter (elastic electrode belt) worn on the subject's chest, and a receiver watch-like monitor worn on the experimenter's wrist. HR data were downloaded via the Polar Interface Plus™ serial-port data-transfer cradle with Polar Training Advisor™ integrated data analysis software. Total elapsed time and simulated lap-time data were logged via stopwatch timer and split-recording features of the Accurex-Plus (synchronized with all HR data recordings).

2.4. Design and test presentation

The study utilized a single factor within-subjects design. Simulated driving conditions in an everyday cruising mode included: daytime hours, bright sunshine weather conditions, moderate pedestrian activity, and no additional traffic. The simulation employed a virtual VW New Beetle, including: automatic transmission, dash-board digital speedometer, rearview mirror, and life-like engine-motor revs. On the right lower quadrant of the display was a small Chicago city-map indicating the current grid-position continuously updated in real-time. It should be noted that map reading was not part of design (the route used was a continuous 'ring' road which did not require left- or right-turns). Total simulated driving time per subject was approximately 90 min., encompassing eight-laps of a 6-mile ring-route (3.5 miles of a 3-lane boulevard expressway + 2.5 miles of an interstate highway). The route used is highly accurate in detail but emulates a 50% scaled-down model of Chicago area and city-center (verified by 'Chicago and Lake Front Vicinity' street-map, © 1998 Automobile Association of America). See Fig. 1. During the laps subjects simulated driving under one of four conditions: "NM" no background music (engine-motor at ± 30 dBA); "MUS1" slow-tempo music (≤ 70 bpm at ± 85 dBA); "MUS2" medium-tempo music (85–110 bpm at ± 85 dBA); or "MUS3" fast-tempo music (≥ 120 bpm at ± 85 dBA). It should be noted that engine motor sound effects were present (but at times masked) in all music conditions. Music conditions were counter-balanced to offset effects of presentation order and acclimation to music tempo.

2.5. Procedure

Each experiment ran for approximately 120 min. consisting of six segments: (a) short oral briefing; (b) fitting of HR monitor; (c) completion of 10-item descriptive information questionnaire; (d) training period (ca. 10 min, 1 lap); (e) experimental task (ca. 90 min, 8 laps); and (f) debriefing. On a typical trial, a subject was exposed to the following sequence of events. After completing a short one-lap training segment, and upon entering 'Sector A' of the course, the start

¹ It should be pointed out that changes in physiological parameters (such as HR) have been shown to predict driving performance impairment, and correlate to lateral position and speed changes (Brookhuis & de Waard, 1993; de Waard & Brookhuis, 1991). The precision and accuracy of Finnish designed and manufactured Polar portable wireless heart rate monitors have been found to correlate (coefficients 0.97–0.99) with various clinical apparatus including stationary ECGs and mobile Holter ECGs (Laukkanen & Virtanen, 1998).

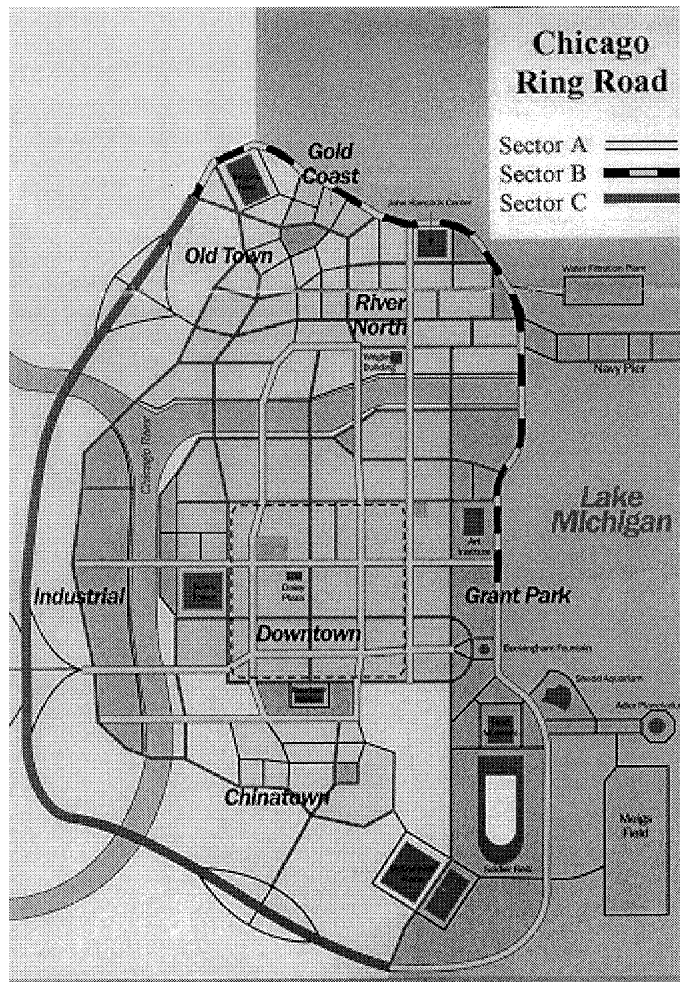


Fig. 1. Chicago ring road driving course.

of the eight-lap experiment was verbally acknowledged. A timer was activated which clocked the total elapsed time of the experiment. When the subject reached 'Sector B' a new condition was introduced (NM, MUS1, MUS2, or MUS3). Upon entering 'Sector C' a lap/split-timer was activated, and then closed upon completion of the simulated interstate highway. Any music that had been initiated was switched off (i.e., music exposure was exclusive to Sectors B-C, while Sector A served as a filler between music conditions in an attempt to offset any effects of the previous music condition). The completion of interstate highway segment signaled the on-set of the subsequent lap-cycle. Previously, subjects were instructed to simulate normal lawful driving; they were informed of municipal speed-limits (30 mph) and interstate highway speed-limits (65 mph). During the trials the experimenter observed and manually recorded the number of virtual traffic violations committed by each subject; the experiment was not 'blind' (i.e., deaf) to the auditory aspects of the simulated driving conditions.

2.6. Analysis

Velocity (MPH) of simulated interstate highway driving was calculated as the consequent of distance divided by time. Heart rate (HR) data of Sector C was downloaded from the Polar Accurex-Plus™ and collated for every subject in every condition. In addition, a measure of heart rate fluctuation (HRF) was calculated from the mean standard deviation of all 15 s HRs in each condition. The frequency of virtual traffic violations – collisions (ACs), lane crossings (LNs) and disregarded red traffic-lights (RLs) – for each subject in each condition were tallied. Each set of variables was entered into separate repeated measures analysis of variance (ANOVA).

2.7. Results

The results of Experiment 1 relate to three categorical areas: physiological data, driving performance, and vehicular control.

1. *Physiological data.* HRs and HRFs for each subject in each condition were entered into separate repeated measures ANOVAs. No main effects were found.
2. *Driving performance.* MPH for each subject in each condition was entered into a repeated measures ANOVA. No main effects were found.
3. *Vehicular control.* ACs, LNs, and RLs for each subject in each condition were entered into separate repeated measures ANOVAs. While no main effects were found for ACs and LNs, a trend was seen whereby the frequency of collisions (i.e., percentage of subjects involved in virtual accidents) increased with the acceleration of music tempo (MUS1 = 25%; MUS2 = 30%; MUS3 = 35%). However, a significant main effect of tempo was found for RLs ($F_{(3,55)} = 3.04$, $MSE = 0.4651$, $p < .05$). See Fig. 2. This later finding demonstrates that 20% of the subjects violated an average 2.5 red-lights when no music was heard, 35% of the subjects violated

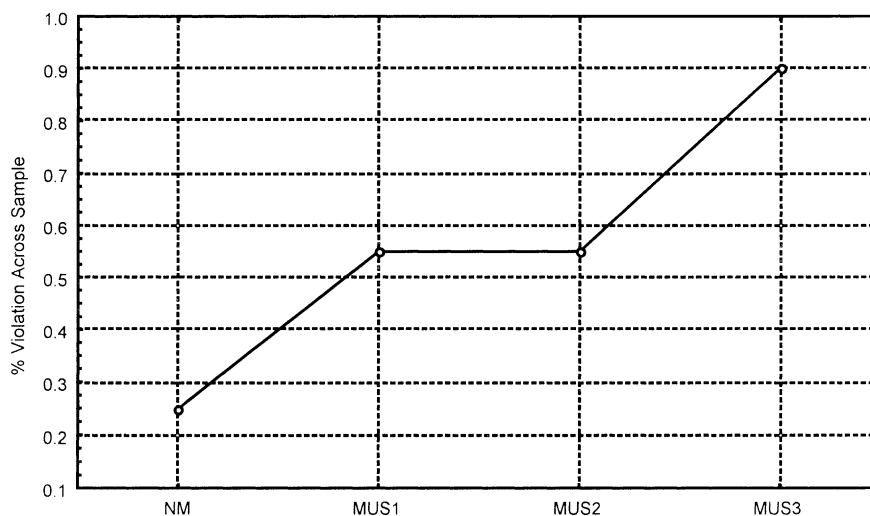


Fig. 2. Experiment 1, main effect of music tempo for disregarded RLs.

an average 1.6 red-lights with slow-paced music, 45% of the subjects violated an average 1.2 red-lights with medium-paced music, and 55% of the subjects violated an average 1.8 red-lights with fast-paced music.

2.8. Discussion of Experiment 1

The main result of Experiment 1 concerns the effects of music tempo on the number of disregarded RLs during simulated driving. One might assume that such effects were caused by higher levels of distraction rather than increased physiological arousal (especially since no effects of HRs or HRFs were seen). This surprising lack of effects, especially in regard to simulated driving speed, warrants further examination and consideration. Perhaps the dash-board digital speedometer on the visual display constricted the drivers to moderate speeds (67 mph) in close proximity to the declared speed limits (65 mph). Perhaps the music itself, or music tempo, might affect musician-subjects differently than what was expected of everyday subjects during simulated driving. For example, neuroscience research long ago acknowledged a general differential neuroprocessing for music among musicians (Bever & Chiarello, 1977; Sergent, 1993). More recently, Micheyl, Carbonnel, and Collet (1995) suggest that specific perceptual processes of music among musicians in regard to more adaptive behavior of everyday situations exists. Accordingly, their intensity sensation appears to decrease less over time (a function referred to as loudness adaptation) in comparison to non-musicians. It is entirely conceivable, then, that from their formal musical training, daily practice, and instrument proficiency, musicians have learned to monitor and control psychomotor responses characteristic of momentary shifts in music tempo. Hence, formal music training should be more carefully considered in empirical investigations involving music tempo and vehicular control. These considerations, related to visual display and sampling, led to Experiment 2.

3. Experiment 2

3.1. Participants

Twenty-eight ($N = 28$) undergraduate students participated in the study for course credit. None had formal music training beyond two years of classroom-music during elementary school, nor had any received instrument lessons beyond one year. On average, they were 25 years old (S.D. = 4.5803), with a majority (65%) being women (a gender-bias attributed to more female students registered in Humanities electives). The subjects had a passenger-car license for an average 7 years (S.D. = 2.7217), and nearly all (92%) reported to have had no previous traffic-related judicial action taken against them. All of the subjects reported to listen to music while driving: 89% reported they drive with music 'all of the time', and 11% reported they drive with music 'most of the time'. The majority (73%) reported they listen to moderate-tempo (85–110 bpm) music, at medium-intensity (50–60 dBA) sound levels. However, 25% reported they drive while listening to fast-paced (120–140 bpm) music, and at higher intensity levels (85–95 dBA). Further, 32% reported they have customized their car with a radio/disk-player or CD-changer, and 42% reported they have upgraded the audio speaker system with a custom configuration. The music genre most

frequently reported for drive-time listening was ‘80–90 s Rock’ (34%), ‘Hebrew Rock’ (29%), and ‘Israeli Popular Songs’ (13%). It is interesting to compare these subjects to a similar sample participating in an early 1960s study (Brown, 1965) whereby only 37% reported they own or ‘use’ a car radio.

3.2. Methodology

The stimuli, apparatus, design, test presentation, procedure, and statistical methodology of Experiment 2 were the same as used previously in Experiment 1, with four exceptions: (1) the computer used to control the experiment was replaced by a DeskPro (Compaq) desk-top PC computer (Pentium III EY 666MMX, Creative EMU10K1 audio processor SoundBlaster Live/Live!DriveII Platinum soundcard), with external AC/powerd full-range (40–20 K) multi-media speakers (Yamaha YST-MS28 consisting of two 2" satellite speakers at 5 W, and one 5" sub-woofer at 15 W), and a 17" Flat SVGA monitor (Compaq S710); (2) two items about vehicular audio equipment were added to the pre-existing 10-item questionnaire; (3) the dash-board digital speedometer was removed from the visual display, and hence municipal and interstate speed-limits were not conveyed but rather subjects were directed to simulate normal driving, to abide by safety and highway codes, and to exhibit maximum vehicular control; and (4) a speed estimation form for simulated interstate highway driving (scored on a 12-point scale representing 0–120 KPH) was completed by subjects upon conclusion of each Sector C. It should be noted that as the subjects estimated driving speed in kilometers (KPH) all subsequent comparative analyses involving speed calculations converted MPH to KPH.

3.3. Results

The results of Experiment 2 relate to three categorical areas: physiological data, driving performance, and vehicular control.

1. *Physiological data.* HRs and HRFs for each subject in each condition were entered into separate repeated measures ANOVAs. No main effects were found for HRs. However, significant main effects of music tempo were found for HRFs ($F_{(3,81)} = 3.39$, $MSe = 0.7330$, $p < .05$). See Fig. 3. Differences of HRFs were found between the NM ($mn = 3.43$; $S.D. = 1.30$) and combined MUS ($mn = 2.86$; $S.D. = 0.71$) conditions, and these differences were statistically significant ($t = 2.806$, $df = 27$, $p < .01$).
2. *Driving performance.* Speed calculations of simulated performed speed (KPH) and perceived speed estimates (P-KPH) for each subject in each condition were entered into separate repeated measures ANOVAs. No main effects were found for KPH. See Fig. 4. However, when KPH data were re-entered into a repeated measures ANOVA across the three music conditions significant main effects of music tempo for KPH surfaced ($F_{(2,54)} = 3.61$, $MSe = 140.55$, $p < .05$). Further, significant main effects of music tempo were found for P-KPH speed estimates ($F_{(3, 54)} = 7.34$, $MSe = 49.194$, $p < .001$). See Fig. 5. *T*-tests for dependent samples were used to explore the difference (DIF) between KPH and P-KPH data. The results indicated statistically significant differences in every condition. See Table 2. DIF scores for every subject in each condition were entered into a repeated measure ANOVA. No main effects were found.

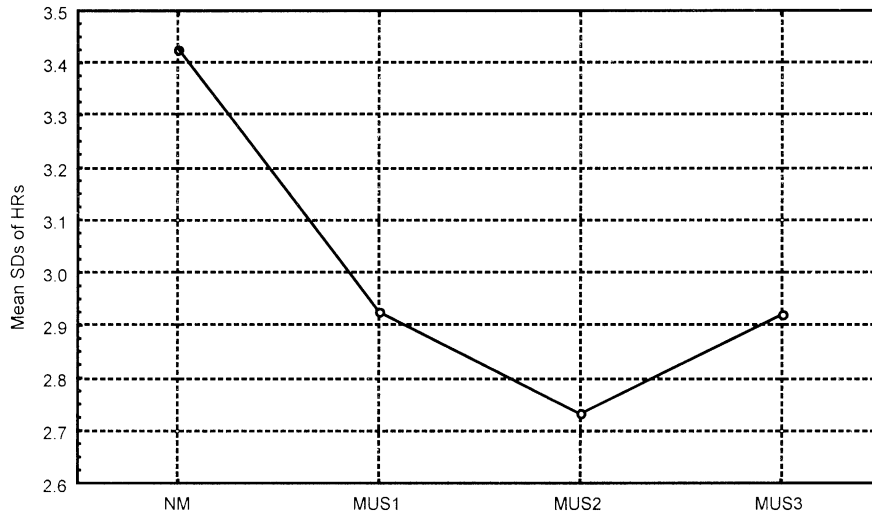


Fig. 3. Experiment 2, main effect of music tempo for HRFs.

3. *Vehicular control.* ACs, LNs, and RLs for each subject in each condition were entered into separate repeated measures ANOVAs. See Table 3. While main effects of music tempo for ACs were not significant ($F(3, 81) = 2.21$, $MSe = 0.1940$, $p = .09$), trends in the direction of the hypothesized effect can be seen. See Fig. 6. In addition, main effects of music tempo were found for LNs ($F(3, 81) = 11.67$, $MSe = 7.4834$, $p < .0001$). See Fig. 7. Moreover, while main effects of music tempo for RLs were not significant ($F(3, 81) = 2.62$, $MSe = 0.7567$, $p = .056$), trends in the direction of the hypothesized effect can be seen. See Fig. 8. Further still, analyses exploring relationships between speed and traffic violations indicated that subjects in a faster-driving group violated significantly more virtual RLs while listening to fast-paced music than subjects

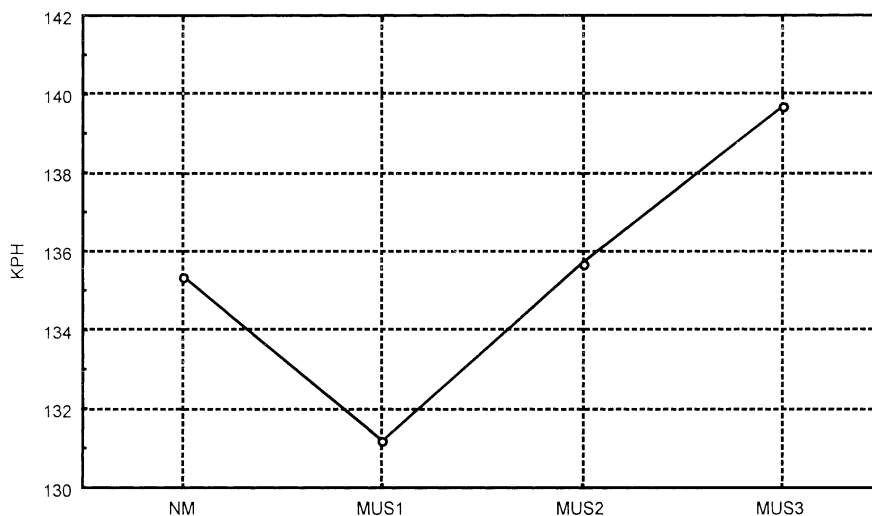


Fig. 4. Experiment 2, main effect of music tempo for simulated driving speed (KPH).

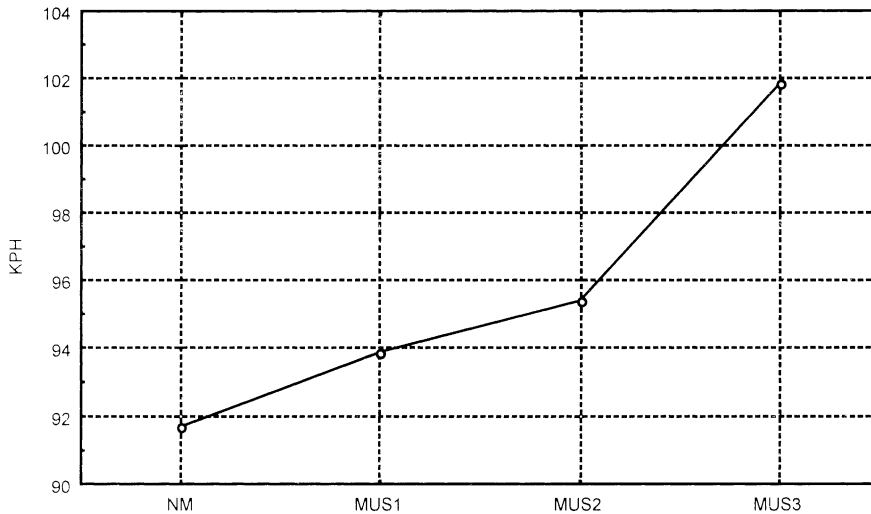


Fig. 5. Experiment 2, main effect of music tempo for P-KPH.

Table 2

Experiment 2, differences between simulated driving speed (KPH) and perceived speeds (P-KPH)

Condition	KPH		P-KPH		DIF		<i>t</i>	<i>df</i>	<i>p</i>
	<i>M</i>	S.D.	<i>M</i>	S.D.	<i>M</i>	S.D.			
NM	144.50	30.18	91.71	10.54	52.79	29.81	7.717	18	.000
MUS1	141.13	32.10	93.88	10.33	47.26	35.16	5.856	18	.001
MUS2	143.11	26.97	95.39	10.65	47.71	28.42	7.319	18	.000
MUS3	147.43	30.98	101.84	12.19	45.59	32.02	6.186	18	.000
Total cases	<i>N</i> = 19								

Table 3

Experiment 2, virtual traffic violations – ACs, LNs, and disregarded RLs

Condition	ACs			LNs			RLs		
	MN ^a	SD	Range	MN ^a	S.D.	Range	MN ^a	S.D.	Range
NM	.07	0.2623	0–1	2.43	3.3602	0–14	.61	0.7880	0–2
MUS1	.14	0.4484	0–2	3.36	3.9927	0–16	.72	0.8968	0–3
MUS2	.14	0.3563	0–1	4.68	4.0373	0–14	.79	1.1661	0–4
MUS3	.36	0.7310	0–3	6.50	6.9735	0–25	1.21	1.2280	0–3

^a MN = violation % of total sample.

in a slower-driving group ($t = 2.997, df = 26, p < .01$). See Fig. 9. Finally, positive correlations were found for average overall simulated driving speed and virtual traffic violations committed across all conditions, as well as between the violation subtypes: KPH–ACs ($r = 0.53, p < .05$); KPH–RLs ($r = 0.52, p < .05$); ACs–RLs ($r = 0.45, p < .05$); ACs–LNs ($r = 0.49, p < .05$).

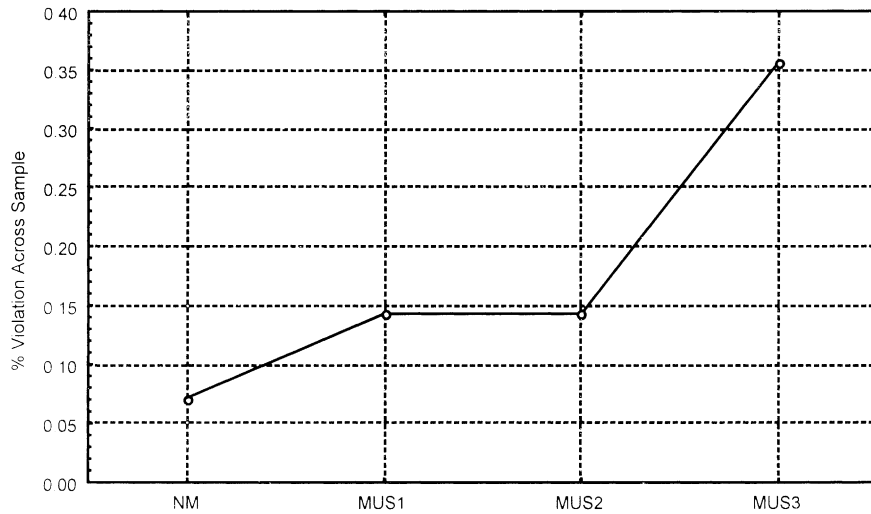


Fig. 6. Experiment 2, main effect of music tempo for ACs.

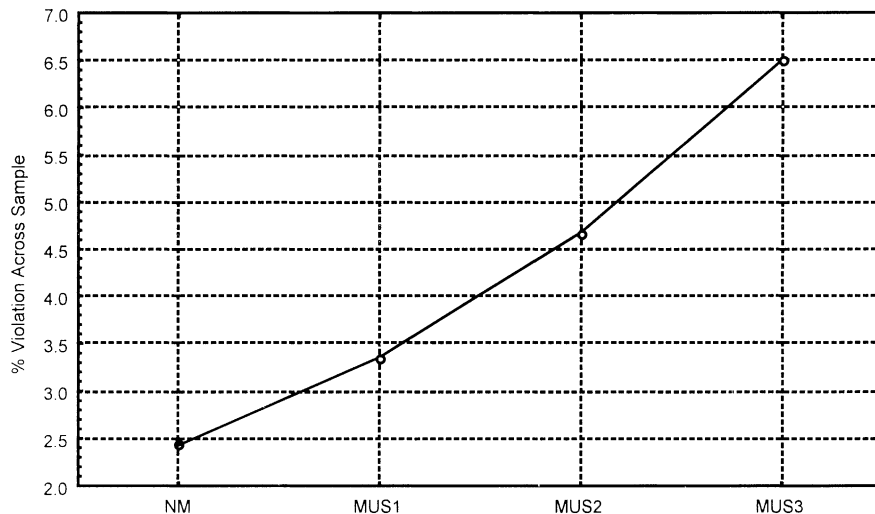


Fig. 7. Experiment 2, main effect of music tempo for LNs.

3.4. Discussion of Experiment 2

Experiment 2 highlights vast differences between simulated driving without music (NM) in comparison to simulated driving with background music (MUS1, MUS2, MUS3). First, HRFs were significantly greater in the NM condition. Second, subjects' simulated driving speed was just as fast without background music as it was with medium-paced background music. Third, subjects were not aware of this inadvertent behavior and they estimated their simulated driving speed without music as quite slow. Therefore, the question as to the validity of NM driving as a

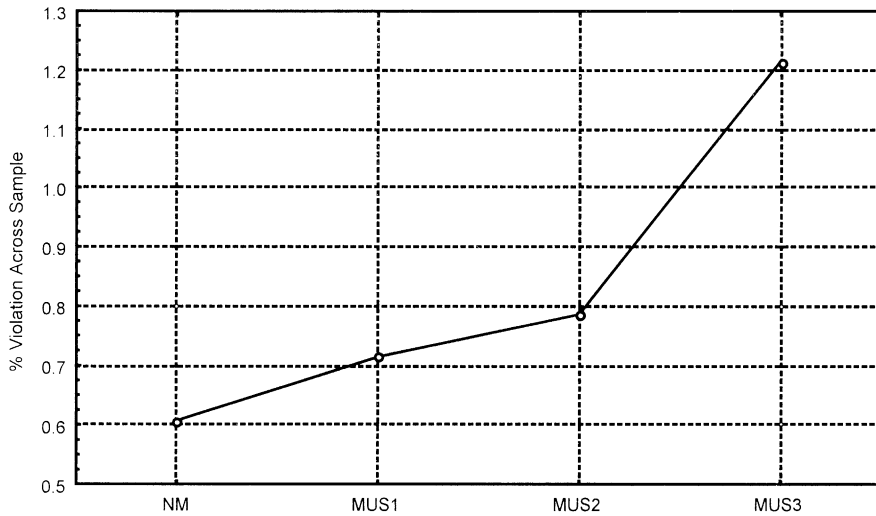


Fig. 8. Experiment 2, main effect of music tempo for disregarded RLs.

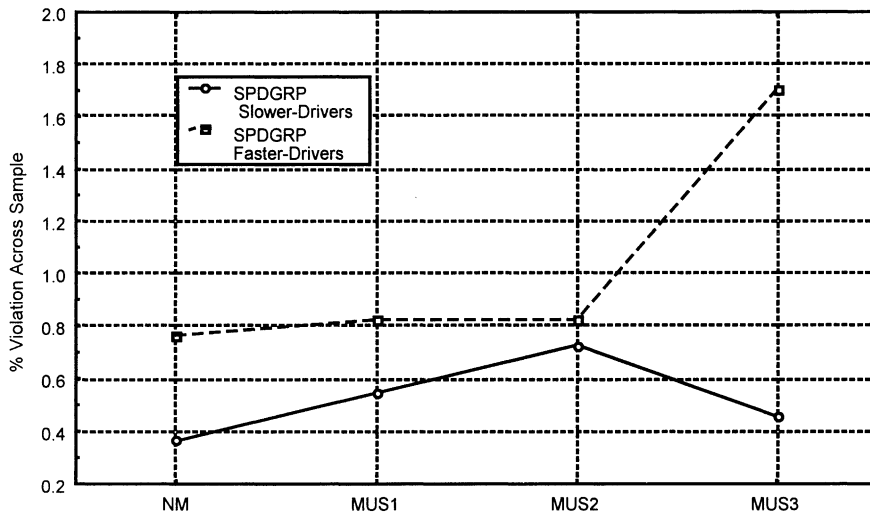


Fig. 9. Experiment 2, interaction effects between speed-group and music tempo for disregarded RLs.

comparative control condition against the effects of background music (MUS1, MUS2, MUS3) on simulated driving speed must be raised. Especially, when considering that decreases in HR variability are related to increased mental effort and stress – and in the current study HRFs are a crude measure of such fluctuations – then it seems clear that simulated driving conditions with music gives way to states that are not present without music. Hence, from the point of view of exploring the effects of music tempo on simulated driving speed, it appears wise to exclude NM from the analysis. Within the empirical context, while the non-music driving condition was originally conceived to represent the lowest level of performance, in retrospect it was clearly a

default of the planned methodology (and hypothesis) to enter NM driving as a ‘control’ and comparison against simulated driving with music. The fact remains that upon re-entering the simulated speed data across all three levels of music tempo, significant main effects resulted demonstrating that as music tempo increases so too does simulated driving speed.

The results of Experiment 2 indicate that subjects tended to significantly under-estimated their simulated driving speed by an average by 45 kph, and these speed estimates consistently increased across music tempo conditions. These findings, then, suggest that while subjects’ perception of simulated velocity was generally affected by music tempo, interference effects (or perceptual inaccuracies) were not necessarily greater with fast-paced music than slow-paced music. Truth be told, background music during simulated driving (regardless of music tempo) seemed to facilitate subjects’ perception of velocity to some extent; estimates without background music were found to be the most inaccurate. Therefore, the presumption about ‘music-situation incongruence’ as a possible explanation for interference effects of music tempo on perception of velocity (i.e., speed-estimate) was not demonstrated.

Experiment 2 demonstrates a positive relationship between simulated driving speed (mean interstate highway driving speed) and virtual traffic violations (total number of collisions and disregarded RLs committed across conditions). In addition, the results demonstrate a positive relationship between the various violation subtypes. Moreover, Experiment 2 demonstrates a significant effect of music tempo on simulated vehicular control as seen in the increased number of virtual traffic violations across conditions: 7% of the subjects committed an average of 1 collision when no music was heard, 11% committed 1.3 collisions with slow-paced music, 14% committed 1 collision with medium-paced music, and 25% committed 1.4 collisions with fast-paced music; 60% of the subjects crossed lanes on average 4 times when no music was heard, 72% crossed lanes 4.7 times with slow-paced music, 93% crossed lanes 5 times with medium-paced music, and 93% crossed lanes 7 times with fast-paced music; 39% of the subjects violated an average 1.6 red-lights when no music was heard, 47% violated 1.5 red-lights with slow-paced music, 39% violated 2 red-lights with medium-paced music, and 61% violated 2 RLs with fast-paced music.

4. General discussion

4.1. Summary

Anecdotal evidence points to the fact that when most people drive they find themselves simultaneously thinking about their everyday affairs and concerns, telling a story, doing mental calculations, trying to remember something, monitoring a football match, or listening to the news radio. It is especially interesting that current surveys depict a fairly new phenomenon involving unaccompanied automobile driving as the most popular and frequently reported location for listening to music. Perhaps with this in mind, drivers today outfit their car for enhanced audio reproduction with CD players and custom-fitted stereo speakers. Far too often we hear an automobile even before we see it, and this situation is not only annoying to pedestrians and other drivers, but perhaps represents a characteristic driver-profile associated with reckless driving-behavior. While not much is known about the effects of music intensity on driving performance, studies tend to report that loudness leads to a decrement of automotive control. Yet, intensity is

not the only music parameter, and there is every possibility that additional stimulus properties of music – such as tempo – might also contribute to increased driving risks.

Most recently, Recarte and Nunes (2000) found that among other causes, errors in detecting relevant information can occur because of internal distraction from visual perception (which is without a doubt the main source of information when driving). Accordingly, vehicular control diminishes when attention is focused on irrelevant driving information, as any reduction in visual processing implies less availability of vital information. Recarte and Nunes suggest that music listening might be a format to facilitate driver's focus of attention on the external environment (rather than on internal perceptions or mental tasks). Unfortunately, their line of thought represents a lack of understanding about music and the cognitive processing of music. First, when listening to a piece of music drivers are immersed in much cognitive work including aural analysis and processing of the music components at various levels related to understanding, operations of short- and long-term memory, and emotions. In addition, extra-musical associations continually surface from music stimuli.

Clearly, not all music is of the same genre, nor does every exemplar within each style satisfy the listener to the same extent. For example, some music pieces are more arousing than others, and music-evoked arousal has as much to do with the temperament of the listener, as it does with the circumstances and environment of the exposure. Arousing music is more cognitively demanding on the driver because of the sheer magnitude of salient features presented, the greater number of temporal events which must be processed, and the frequency of temporal changes which require larger memory storage. The effect of music on drivers seems to be multi-dimensional. Beyond the level of 'arousal' which has traditionally been associated with the stimulus property of intensity, there is also a level of 'distraction' which might be associated with the stimulus property of tempo. This is especially interesting when considering that driving with background music is essentially an issue of applying an aural-temporal stimulus within a spatial-temporal environment involving a specific motor-performance task. Therefore, it might be warranted to consider instances when both music and environmental situation are either congruent or incongruent. This important line of research has not yet caught the imagination of those investigating driving performance, and is of utmost consequence since vehicular activity is particularly the everyday circumstance which requires people to contend with perceptual-linkage (and distortions) which can occur between 'time', 'velocity', and 'distance'.

Connolly and Alberg (1993) demonstrated that a significant role may be played by drivers' comparisons of their own speed with that of other nearby drivers which lead to non-intuitive consequences. They conclude that significant contagion effects exist which affect driving speeds. However, 'rhythmic contagion' effects of music have been acknowledged since ancient times by writers of western and eastern thought (for example, see Plato, xxxx or Shiloah, 1978). Rhythmic contagion has been seen over the history of mankind to relate to both the potential 'power' and 'danger' of music exposure (Boxberger, 1962). Thus, if music stimuli which move at slower levels of perceived activity (i.e., slow tempo) can cause drivers to experience 'time' and 'velocity' in terms of the subjective pace of the accompanying background music, then vital monitoring of internal cognitive timers may be hampered and distort perceptual information (for example, vehicular speed), and result in reckless driving-behavior or perhaps highway fatalities.

A related aspect of rhythmic contagion is 'music entrainment'. Entrainment (or the Huygens Phenomenon ca 1665) is the locking into phase of previously out-of-step oscillators. Music

entrainment, then, is the coupling of a biologically self-sustained endogenously generated rhythm with an external temporal music stimulus (Saperston, 1995). The current study reported a main effect of music tempo for HRFs demonstrating that HRFs were significantly greater for simulated driving without music than with either slow-, medium-, or fast-tempo music. This is an interesting effect, and may partially explain the vast number of violations occurring across music conditions in comparison to the non-music condition. Higher heart rate variability (HRV) has been seen to indicate a healthier cardiovascular system, and more agile response adaptabilities. On the other hand, decreases in HRV are linked to mental effort or stress, and contribute to unstable response aptitudes. Within the context of the current study, the music conditions may functionally induce some form of rhythmic synchrony (or entrainment) constituting a decrease in HRFs (i.e., presented as a crude measure for HRV) resulting in driver distractibility and subsequent impaired performance.

4.2. Main findings of the study

The first main finding of the study is that the tempo of background music consistently affected both simulated driving speed and perceived speed estimate. As the tempo of background music increased, so too did both simulated driving speed and speed estimate. The tempo of background music did not affect perceptual inaccuracies of speed estimate, and the difference between simulated driving speed and perceived speed remained fairly consistent across music tempos. Without background music subjects accelerated to moderately quick speeds, while they perceived their velocity to be fairly slow (i.e., speed estimates were most inaccurate without music). The second main finding of the study is that the tempo of background music consistently affected the frequency of virtual traffic violations. Vehicular collisions, lane crossings, and disregarded red traffic lights were most frequent during simulated driving with fast-paced background music. Subjects in the faster-driving group demonstrated significantly more at-risk simulated driving behaviors with fast-paced background music. In addition, the study reports that music-evoked arousal was not demonstrated during PC-controlled simulated-driving regardless of fast-paced music stimuli (120–140 bpm) at high intensity exposures (± 85 dBA). Finally, the study raises an interesting question about the status of expert musicians when driving with background music: the tempo of background music during simulated driving caused a very different variance of effects among musician-subjects than non-musician subjects.

4.3. Implications of the findings

The current study confirms the effects of music tempo on simulated driving performance and vehicular control. While music-evoked arousal was not confirmed, and hence the research hypothesis was not accepted in its entirety, accelerated music tempo clearly induced increased simulated driving speeds and more frequent virtual traffic violations. Therefore, one could assume that as music intensity has been traditionally seen to account for arousal effects, music tempo might more clearly be seen to account for distraction effects. Shinar (1978) long ago demonstrated that a high percentage of car accidents are due to attention and information-processing failures rather than to a lack of skill in driving performance responses. The distinction of music-intensity

evoked arousal and music tempo-generated distraction is an important line of inquiry for future driving research studies.

The study demonstrated that fast-paced music caused subjects to demonstrate significantly more ‘at-risk’ behavior. Yet, while subjects were aware that their simulated driving was at higher speeds, and correctly estimated these to be fastest when driving with fast-paced background music, they still underestimated (by an average 45 KPH) just how fast the virtual vehicle was moving. Fast-paced background music not only caused the highest number of collisions and disregarded red-lights, but significantly increased vehicular shifting of lateral position or ‘weaving’ – even on the virtual highway. These findings clearly highlight the effects of rhythmic contagion (and perhaps entrainment) from tempo of music background on simulated driving-behavior.

Clearly the current study was based on PC-controlled simulated driving (in a virtual vehicle on an animated road). Recarte and Nunes (2000) state that researchers must consider how real driving tasks involve specific characteristics including a dynamic environment and observer, a three-dimensional visual field, and distinct behaviors related to survival. Accordingly, studies performed in simulated driving environments can not guarantee that the attentional requirements are equivalent to real driving – especially as far as the perception of risk is concerned, or in regard to time-sharing strategies. Moreover, stimuli presented on a computer screen are perhaps easier overwhelmed by music stimuli than on-the-road driving stimuli. That is, perceptual cues may be very different in the laboratory where engine noise and revs, vibrations, motor feedback, pedestrian density, weather conditions, and additional traffic are either controlled, tuned-down, or eliminated altogether. Nevertheless, the current studies points to a rather under-researched area of driving behavior.

The number of music-related automobile accidents and highway fatalities is not a known statistic. This variable may be too difficult to account for when investigating the circumstances in the aftermath of driving casualties and tragedies. Perhaps police investigators themselves are not mindful of the risks associated with music. Further, drivers’ education courses do not warn learners about the risks involved of driving with music. Other risks are openly expressed, such as those associated with alcohol consumption prior to driving, and usage of mobile communications during driving. Neither are novice or experienced drivers aware of the effects that background music may have on their perception, performance, and control of the vehicular environment. Such a situation is especially distressing when considering that: (1) current lifestyles have placed men and women more often behind the steering wheel than in past decades; (2) more often than not drivers choose to travel with background music playing in the vehicle, and pre-plan which cassettes or CDs to take with them on road trips; and (3) most drivers listen to highly energetic ‘aggressive’ music consisting of a fast-tempo and accentuated beat, played at strong intensity levels of elevated frequencies and volumes. The effects of background music on driving performance and vehicular control must, therefore, become a priority for future research studies investigating driving behavior and performance.

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