A performance analysis of In-Car Music engagement as an indication of driver distraction and risk

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Abstract

Drivers engage in a host of driving-unrelated tasks while on the road. They listen to music, sing-along, and accompany songs by pounding-out drum-kicks and syncopated rhythms on the steering wheel. However, there is controversy over in-cabin music: Does background music facilitate driver performance via increased arousal leading to more focused concentration, or cause distraction placing drivers at greater risk. In an effort to shed light on the debate, the current study evaluated music engagement by employing Music Performance Analyses with audio recordings from three simulated driving conditions. The results indicate that as the perceptual demands of the primary driving task increased, the secondary music activity was hampered, and subsequently sub-optimal vocal and percussive performances were demonstrated consisting of intonation errors, rhythmic inaccuracy, lack of synchrony, inconsistent and unstable temporal flow, neglect of text, and lyric replacement. The findings seem to point out that drivers allocate greater reserves to music than previously considered, and as drivers do not withdraw altogether from music engagement under high-demand driving conditions, driving may be under-resourced. Exploring active music engagement while driving might assist traffic safety researchers in decoding the effects of In-Car Music on driver behavior.

1. Introduction

Drivers engage in a host of driving-unrelated tasks while on the road. Walsh (2010) argued that especially when drivers are alone, they not only listen to music but sing along in a karaoke-like fashion, as well as tap along on the steering wheel. Brodsky (2015) pointed out that as if participating in the performance itself, drivers often accompany songs by singing the melody or vocalizing background fills and runs (which he coined Car-aoke), and they pound-out drum kicks and syncopated rhythms on the steering-wheel (or gearshift or dashboard), play ‘licks’ and solos in an air-guitar fashion, and even dance in their seat. Car-audio has developed from the 1950s throughout the 1990s as an integral feature component of the automobile. From the turn of the millennium, surveys have reported that the most popular location where people engage in music listening is the car (for a comprehensive review, see: Brodsky, 2015). As drivers envisage feeling secure and protected by their automobile, the last thing they would ever think about is how safe it may be to turn on the radio, toggle a channel knob, adjust the volume, flip a cassette tape, swap a CD, or thumb-scroll through a playlist – and sing along with the music. It does seem that a central belief of drivers is that background music is as much of a natural and fundamental constituent of driving as is accelerating, looking ahead, steering, and braking. Today there are countless fixed on-board in-cabin technologies (i.e.,

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automotive entertainment features), as well as portable ‘nomadic’ devices that connect to in-cabin systems via Bluetooth; all of these offer drivers an opportunity to engage with music. Among the sources that provide music tracks for drivers are broadcast and satellite radio, compact disk players, digital music players, personal flash disks, smartphones, and notebook tablet computers.

While there seem to be a handful of benefits for driving with music including entertainment, stress reduction, combating boredom, counteracting fatigue, and emotional regulation (Clarke, Dibben, & Pitts, 2010; Dibben & Williamson, 2007), by adding music to a milieu consisting of driver performance and vehicular control within a highly dynamic and potentially hazardous traffic-based road environment, there may also be some shortcomings as far as personal safety is concerned. For example, Brodsky (2015) delineated four contraindications of In-Car Music: structural distraction resulting from poor HMI ergonomics and mechanical configurations; perceptual masking; capacity interference to central attention subsequent to overtaxed cognitive faculties; and social diversion. Further, Brodsky documented evidence for three ill-effects that hamper drivers: Music-evoked Driver Arousal, Music-generated Driver Distraction, and Music-induced Driver Aggression. Nonetheless, there is a controversy about the utility of In-Car Music within the annals of the transportation and traffic safety literature. Thus far, there has been no overriding verdict regarding the adaptive versus maladaptive nature of in-cabin music background. For example, Unal (Unal, de Ward, Epstude, & Steg, 2013; Unal, Platteel, Steg, & Epstude, 2013; Unal, Steg, & Epstude, 2012) claimed that In-Car Music facilitates driver performance, and demonstrated increased arousal leading to more focused concentration. The studies revealed drivers to intuitively implement cognitive strategies to reduce task-demands on the road by blocking-out auditory distracters such as radio broadcasting and music background. Unal et al. concluded that In-Car Music does not impair driving performance. Further, in a highly cited survey study, Dibben and Williamson (2007) determined that unlike verbal conversation with either accompanying passengers present in the vehicle or with a distant caller by which drivers are required to sustain a necessary level of attention, in-cabin music engagement offers drivers much more flexibility to ‘start and stop at will with no ill consequences’. On the other hand, Hughes, Rudin-Brown, and Young (2013) found that singing while driving altered driving performance and significantly impaired hazard perception. Moreover, Brodsky, 2002, 2013, 2014, 2015, Brodsky & Kizner, 2012; Brodsky & Slor, 2013 demonstrated that background music caused distraction, and placed drivers at greater risk for increased driver miscalculation, inaccuracies, deficiencies, errors, traffic violations, and driver aggressiveness. Brodsky and Slor presented evidence that listening to preferred music hampered perceptual motor control leading to a decrement of vehicular performance with increased incidents, events, and near-crashes.

It should be pointed out that all research efforts thus far have investigated the extent to which passive listening affects driver behavior and vehicular control. That is, driving while background music was heard in the cabin. In general, this body of research puts forth studies that have employed simulated driving tasks, driving simulators, closed-circuit test-tracks, and real-world on-road ‘naturalistic’ driving – all the while monitoring braking RTs, cruising speed, longitudinal acceleration, lateral deviations from the mid-line of the lane, and various driver deficiencies. For the most part, these investigations have been modelled on platforms and paradigms used previously to examine the effects of mobile phones in vehicles. However, one landmark study from the later corpus went further than all the others in that it documented the dysfunctional impact that ‘conversation’ had on driver behavior. Crundall, Bains, Chapman, and Underwood (2005) examined if drivers adapted to the flow of conversation while driving on urban roads, and subsequently demonstrated how drivers adjusted to traffic-related environmental demands. Crundall et al. demonstrated that depending on the traffic conditions, drivers tended to slow down the pace and density of discourse; they referred to the phenomenon as ‘conversational suppression’. This single effort not only revealed the degree to which engaging in verbal conversation as a secondary task impinged on the primary task of controlling a vehicle, but was instrumental in confirming that increased risks of mobile phone use were well beyond what had been accepted by federal safety agencies as pertaining to physical structural distraction caused by mechanical manipulation of hardware. Namely, Crundall et al. discovered that conversation itself was a contributory factor for inattention to the road through capacity interference of cognitive faculties that were otherwise engaged. Strayer and Drews (2007) confirmed that when drivers become involved in a phone conversation, their attention is drawn away from the information in the driving environment that is necessary for safe operation of the motor vehicle. Then, in a later study Strayer et al. (2013) rated the workload of several auditory-based secondary tasks and employed the Cognitive Distraction Scale (items scored between 1 and 5) for such ratings. They found listening to talk radio (1.20) or an audio book (1.70) associated to small cognitive distraction. Yet, Strayer et al. also found that when drivers conversed with a friend on a hands-free (2.30) or hand-held (2.40) or cell phone, or when they conversed with a passenger (2.35), then cognitive distraction was measured as moderate. Finally, driver interaction with voice-command personal assistant operating systems (3.10) were measured as a large cognitive distraction. Therefore, given the above-mentioned debate about the utility of music background while driving, it would seem warranted to explore driver behavior in a more active mode of music engagement rather than as passive listening. Such an effort may lead to a greater understanding concerning the consequences of In-Car Music on driver behavior.

In the current study, the secondary driving task was placed in the forefront of examination. It was expected that as the perceptual demands of the primary driving task increase from stationary parking through low-demand driving to high-demand driving, music performances of drivers would be hampered. For example, one might envision a decline of music performances as revealed by corrupt executions consisting of intonation errors, rhythmical inaccuracies, lack of synchrony,
inconsistent and unstable temporal flow, lyric replacement, or neglect of text altogether. Namely, when drivers experience higher demand driving conditions, while attempting to prioritize undertakings related to driving, as they may be either unable or unwilling to disengage from the aural background and music activity altogether, they will subsequently demonstrate persistent suboptimal vocal and drumming performances. Such a preposition stands in direct opposition to conclusions published in the literature, stating that when drivers experience higher demand driving conditions, in their attempt to cope with the primary driving task they will disengage from secondary music activity at will with no ill-consequences by altogether blocking out aural backgrounds as a strategic maneuver. It is important to point out here, that the current study not only underlines driver engagement with music, but also pioneers Music Performance Analysis (MPA) as a means to examine the secondary music-related driving task. MPA is a widely accepted methodology associated with the fields of Musicology and Music Performance Science. The current study, then, attempts to transfer MPA from the arena of artistic performance that is centered on assessing highly developed musical skills and life-long expert proficiencies, to the more mundane everyday traffic-related setting involving persons without such explicit training. It is imperative to call attention to the fact that the present investigation solely focuses on establishing MPA as an ecologically sensitive platform to measure driver behavior when engaged in music activity. That is, the study does not explore associative performance indices measuring driver deficiencies or decrement of vehicular control. One the one hand such a focus is essential to advance a proof of concept effort regarding MPA, while on the other hand – and similarly to the Crundall et al. study – it is acknowledged that without indicators of vehicular performance the current findings cannot reveal if the hampering and/or disruption of the secondary task either implies neglect or prioritization of the primary task.

2. Study 1: Car-aoke vocal performance

The main purpose of the study was to assess singing-along to music as a secondary-task while simulating driving. It was expected that Car-aoke vocal performances would become more corrupt with an increased percentage of intonation and text-lyric errors as driving conditions become more demanding.

2.1. Methodology

2.1.1. Subjects

Originally 29 undergraduates participated as drivers; they received extra course credit. Three inclusion criteria were: Driver’s License (valid for at least three years), General Health (no pharmaceuticals prescribed for hyperactivity or high blood pressure); and Sing-ability (willingness to sing aloud). During the study, the data of seven participants were dropped from the set: hardware failure \( n = 2 \), simulator sickness with dizziness or nausea \( n = 1 \), remiss in remembering lyrics at baseline \( n = 2 \), and non-compliance of driving tasks within the allocated time \( n = 2 \). The audio data of the remaining 22 participants went forward into analyses. Yet, after examining vocal performance errors (described in more detail below in Section 2.4), three participants with scores indicating \( \geq 90\% \) errors at baseline were removed from the data set. The final sample of participants \( N = 19 \) were between 23 and 27 years old \( M = 25.5, SD = 1.27 \), and 68% females. They held licenses for an average 7.2 years \( SD = 1.72, range = 3–10 \). By self-report, none had been charged with a serious traffic offense, 32% had never been in an incident, but 47% experienced a ‘fender-bender’. The overriding majority (89%) affirmed they always listen to music when driving, described as fast-paced songs reproduced at loud volumes. Most specifically, 88% claimed most of the time they drive while singing along with songs from sources including music radio broadcast, CDs, and MP3 players. The undergraduate participants were not music majors; while 68% reported to have never had previous music experience, the other 32% claimed to have learned an instrument during childhood for roughly 2.3 years \( SD = 4.18 \).

2.1.2. Equipment

The study employed a simulated driving task with a PC-controlled video game (Midtown Madness ‘Chicago Edition’, Microsoft) in a single-user cruise mode without other cars on the road. The vehicle emulated a New Beetle (Volkswagen) cockpit with a realistic-looking dashboard including digital speedometer, gauges, and a rear-view mirror. The software was run on a desk-top PC with a 17” flat monitor, coupled to a MOMO® Force Feedback Racing steering wheel with accelerometer and brake pedals (Logitech). Aural signals including environmental driving sounds (vehicle and roadway), the background music, and the drivers’ vocal performances, were all routed and subsequently equalized with a 5-channel mixer (Samson) through a 4-channel stereo headphone amplifier (Samson) to RH-5MA full-frequency \( 20 \text{ Hz}–20 \text{ kHz} \) supra-aural \( 40 \text{ mm speakers} \) closed-back monitor headphones (Yamaha). Vocal performances were captured with an H2 (Zoom) digital recorder to SD memory cards as 24bit/96 kHz linear PCM (.wav) files. Background music (MP3 files) were controlled and reproduced via an iMac (Apple) desktop computer.

2.1.3. Music stimuli

The study employed three well-known popular songs that everyone from the target sample could easily sing. Initially, Pop Radio song charts were considered as a source to enlist a set of suitable songs. However, current Billboard listings contained tunes that were not necessarily as popular or well-known as the more ‘classic’ Pop/Rock songs of previous years. In addition,
many songs ranked high in the charts were not very easy for everyday people to sing. Thus, a stimuli development procedure was undertaken.

2.1.3.1. Pre-study pilot. A list of eleven songs was assembled, based on five criteria: Language (sung in local Hebrew vernacular); Popularity (recorded by a well-known artist having appeared on a certified best-selling album); Complexity (structured on a simple architectural form [such as introduction, verse, chorus, verse, chorus, coda]); Diapason (within a vocal range not extending beyond one-and-a-half octaves); and Vocal Rendition (not containing elongated instrumental solos void of lyrical text). These criteria are similar to those used by Hughes et al. (2013). Employing an on-line survey platform (Qualtrics), the song titles were presented to 75 young adults with comparable demographics as the target sample. The respondents were undergraduates between 20 and 30 years old (M = 24.97, SD = 2.01), and 73% female; they received extra course credit. Each participant ranked the popularity of the songs on a 4-point scale (1 = ‘Not At All Popular or Well-Known’, 4 = ‘Highly Popular and Well-Known’). The popularity and familiarity of the songs was very high (M = 3.47, SD = 0.21, Range = 3.11–3.80). Although no time limit was imposed, the maximum time taken to complete the survey was ten minutes.

2.1.3.2. 3-Exemplar stimuli set. The most popular and familiar ‘Top-3’ songs from the pre-study pilot were selected for the study. The songs were performed by two male vocalists. The selected songs were: ‘Ani Ve’ata’ (Arik Einstein), ‘Oof Gozal’ (Arik Einstein), and ‘Ve’ech Shelo’ (Ariel Zilber). On average, the songs were four minutes long (M = 3:58, SD = 0:56, Range = 3:20–4:20), contained roughly 100 words in the lyrics (M = 98, SD = 27, Range = 71–127), and about 200 notes in the melody (M = 215, SD = 63.13, Range = 150–276) placed within an average 95 measures (M = 94, SD = 13.45, Range = 79–105).

2.2. Procedure

Prior to onset, a university Internal Review Board approved the study. Two nights before the experiment, each participant received an email with the lyrics and a YouTube web-link for each song. This method has been previously employed by Hughes et al. (2013). The participants were instructed to practice singing the songs during the following two days. Simulated driving was conducted in an acoustically treated Music Psychology Lab. Upon arrival, every participant signed an Informed Consent Form, and completed a 1-page demographic questionnaire. The participants were requested to choose two of the three songs, place headphones over their ears, and sing a full rendition of each song with the same video clip accompaniment they were sent previously. They sang from memory without printed lyrics. These performances were considered the ‘No-Drive’ (ND) condition as if singing in a stationary parked vehicle. The participants were told that no one, not even the experiment monitor, could hear them sing as they were isolated behind a soundproof glass partition. The experiment monitor was in clear sight on the other side of the window. However, the participants were informed that their vocal performances were being recorded for later musicological evaluation. All recordings were made in such a way as to isolate the vocal singing from all other aural stimuli including the background music accompaniment. During this phase, the computer display was turned off (i.e., black screen). The two ND vocal performances were performed in a random order. Thereafter, the display was switched on, and participants viewed a traffic-related scene from behind the vehicle windshield. They viewed roadways, pedestrians, and traffic lights. They heard street sounds, and felt the vibrotactile pulsation of engine hum. Then, a short oral briefing concerning the driving hardware (such as steering wheel, and accelerator/brake pedals) ensued. The participants were instructed to obey traffic regulations (i.e., ‘drive in the right lane’, ‘stop at red lights’, ‘abide traffic signs’, ‘do not exceed 50mph’). Finally, every participant drove a 5-min practice trial.

The active experiment was carried out as two trials reflecting driving conditions counter-balanced across the sample. In each trial, the drivers were asked to sing along with one of the two songs (presented in a counter-balanced manner, albeit juggled between three songs across the sample). One trial was considered ‘Low Demand’ (LD) driving in which participants cruised freely throughout a city center while continuously singing; the trial ended upon conclusion of the song. The other trial was considered ‘High Demand’ (HD) driving in which participants were required to perform a dual-task by driving and navigating (map reading) to a destination plotted on an A4-sized street map placed to the right of the computer display screen. There were two possible destinations counter-balanced across the sample. It should be pointed out that in the lower right quadrant of the screen was a small (6 x 6 cm [2.5 x 2.5 in.]) animated GPS application for drivers to monitor their location while visually scanning the street map. The trial ended when they reached the designated spot; the majority of drivers (77%) required two song repetitions before parking near the final destination.

At a later date, the recordings of all three vocal performances for each driver were cropped as separate audio files per condition (ND, LD, HD) with SoundForge (Sonic Foundry). The audio (.wav) files were not edited for sound quality nor modified in any way.

2.3. Music performance analysis

The overriding goal of the study was to compare variances between the three vocal performances recorded during baseline and two driving conditions (ND versus LD/HD), as well as to contrast the performances of the driving conditions themselves (LD versus HD). Such a musicological evaluation required the examination of audio files and scoring for errors on music notation. One aspect of MPA targets errors identified on a categorical basis relative to the original source. In this case,
there were four ‘Score Based Errors’: Pitch Substitutions (singing a note with the wrong pitch than as written in the score); Deletions (failure to sing a note as written in score); Intrusions and Additions (adding notes to the performance that do not appear in the score); and Timing Errors (performing notes with onsets $\geq 150$ ms before/after the expected time). The latter accounts for Expressive Asynchronies that typically appear $\leq 100$ ms before/after expected time. An additional fifth category was employed reflecting errors of the lyrics indicating inaccuracies of the text by word-replacement or neglect.

MPA was undertaken by an independent expert who was both blind to the goals of the study, as well as to the context (i.e., simulated driving). The adjudicator was a 56-year-old professional musician with absolute hearing, 51 years of experience as a pianist, 36 years of experience accompanying vocalists at auditions, and 35 years of experience as a Répétiteur. A répétiteur is a pianist-accompanist responsible for coaching singers during musical production rehearsals. As a vocal coach, the répétiteur is solely responsible for advising singers on how to improve pitch and pronunciation, as well as for correcting errors of notes (intonation), phrasing (rhythm), and text (lyrics).

2.4. Results

Initially, the aural examination of all sound files occupied roughly 5 h of listening time (352 min aural assessment) examining a total of 17,600 notes and 8800 words. For each of the 88 recordings the adjudicator marked score-based errors on the music notation. Subsequently, the data of three participants with scores indicating $\geq 90\%$ errors of intonation already at both baseline ND performances was withheld from further analyses. This strategy was set in place to assure that findings of the study would reflect differences between driving conditions with the least amount of corruption by those who consistently sing out-of-tune. This condition has been referred to as tone-deafness. Such inabilities might indicate problems of processing and/or distinguishing between tones, as well as possible deficits in accurately reproducing vocal pitches by consistently sing ing 1/10th above/below the precise pitch. In the current study, MPA implemented a note-by-note resolution as a unit of measure for identifying errors of intonation and rhythmic properties. Further, a word-by-word resolution was employed as a unit of measure for detecting errors of text-lyrics. Thereafter, both of these calculations were reconfigured as percentages. See Table 1.

Then, error percentages of vocal performances for the melody line per note by condition (with baseline data averaged across both performances) were entered into a repeated-measures analysis of variance (ANOVA). No main effect surfaced: $F(2,36) = 0.2802, MSe = 166.83, p = 0.76, \eta_p^2 = 0.02$. Nor did significant effects surface from post-hoc Tukey tests comparing between the conditions: ND vs LD&HD: $F(1,18) = 2.099, p = 0.17, \eta_p^2 = 0.11$; LD vs HD: $F(1,18) = 0.0302, p = 0.86, \eta_p^2 = 0.002$. Further, error percentages of vocal performances for text-lyrics per word by condition (with the baseline data averaged across both performances) were entered into a repeated-measures ANOVA. A statistically significant main effect surfaced: $F(2,36) = 3.4847, MSe = 29.49, p = 0.04, \eta_p^2 = 0.16$. The effect size of this finding is considered a medium effect. Moreover, a statistically significant effect surfaced from post-hoc Tukey tests comparing between the conditions: ND vs LD&HD: $F(1,18) = 25.70, p = 0.0008, \eta_p^2 = 0.59$; LD vs HD: $F(1,18) = 0.119, p = 0.73, \eta_p^2 = 0.007$. The effect size of the former is considered a strong effect, while the latter difference is non-significant. These findings indicate that memory for lyrics was hampered most when simulating driving activity compared to when seated in a stationary parked vehicle. There were no differences between LD and HD driving conditions.

2.5. Discussion

Study 1 found that vocal abilities of drivers were not as hampered during simulated driving tasks as was initially anticipated. Score-based errors such as pitch substitutions, deletions, intrusions and additions, as well as timing errors, were no greater when engaged in a simulated driving task than when singing while seated in a stationary parked automobile. Hence, one might assume then, that driving does not interfere with Car-aoke, and perhaps vice versa that Car-aoke does not interfere with driving. Nonetheless, other possible explanations cannot be ruled-out. For example, MPA may not be sensitive enough to reveal vocal differences between demand characteristics of driving conditions experienced with simulated PC-controlled driving tasks. Further, there is the possibility that the differences between LD versus HD driving as operationalized in the current study were not diverse enough. Further still, there is a possibility that use of headphones might have made it difficult to completely ignore the music or disengage from it. Finally, the sample size may have been too limited to account for large deviations among drivers. Nonetheless, Study 1 found that memory for lyrics of highly popular and well-known songs were significantly obstructed during driving. That is, compared to ND stationary parking, recordings of vocal performances during both LD and HD drives were significantly corrupted. The findings regarding textual-lyrics clearly indicated that as drivers experienced higher demand driving conditions, not only did they not fully disengage from music activity but they

| Table 1 |
| Music performance analysis: Study 1, Car-aoke. |
| song | low-demand drive | high-demand drive |
| stationary no drive | percentage | percentage | percentage |
| song | 35.5 (20.3) | 32.4 (20.1) | 33.4 (21.9) |
| text | 8.3 (5.9) | 12.7 (7.9) | 11.9 (10.3) |

$^a$  =  Mean percentage of performance errors.
subsequently demonstrated persistent suboptimal vocal performances. Future studies are still needed to investigate if such hampering of a secondary Car-aoke task is as a result of neglect or prioritization of the primary task.

When driving with music, drivers also accompany songs with drum kicks and syncopated rhythms on the steering-wheel, gearshift, and dashboard. Therefore, Study 2 was implemented to highlight percussive drumming performances.

3. Study 2: Percussive drumming performance

The main purpose of the study was to assess drumming-along to music as a secondary-task while driving. The study replicated Study 1. It was expected that as driving conditions become more demanding, percussive performances would become more corrupt with an increased percentage of motor-timing errors.

3.1. Methodology

3.1.1. Subjects

Originally 21 undergraduates participated as drivers; they received extra course credit. The inclusion criteria were the same as Study 1. Again, after examining performance errors, two participants with scores indicating ≥55% errors at baseline (described in more detail below in Section 3.4) were removed from the data set. The final sample of participants (N = 19) were between 21 and 27 years old (M = 23.9, SD = 1.51), and 74% females. They held licenses for an average 6 years (SD = 1.60, range = 3–10). By self-report, none of the drivers had been charged with a serious traffic offense, 52% had never been in an incident, but 26% had experienced a ‘fender-bender’. All of the drivers (100%) affirmed they drive while listening to fast-paced music reproduced at loud volumes. Specifically, 74% claimed they sing-along with the songs, 80% reported that they drum-along as accompaniment, and 48% asserted that they dance-along in the driver’s seat. It should be pointed out that the undergraduate participants were not music majors; 63% reported to have never had previous music experience, while the other 37% who claimed to have learned an instrument reported that their training was during childhood for roughly three years (SD = 4.06).

3.1.2. Equipment

Study 2 employed the same simulated driving tasks and music stimuli as used in Study 1 (described above in Sections 2.1.3.2 and 2.2). However, unlike Study 1 which reproduced music ‘fixed-field’ via headphones, Study 2 reproduced aural signals from vehicles and roadways, background music, and percussion sonorities, via three independent ‘free-field’ sets of amplified speakers. Percussion performances were captured with a Perception 100 (AKG) large diaphragm studio condenser microphone placed centrally in the room coupled to a digital recorder. The recordings were cropped similarly as Study 1.

Study 2 employed CLIPHIT (Korg) sensors for drumming sequences. See Fig. 1. CLIPHIT is an electric drum-kit module employing sensor clip technology that can be attached to any surface, transforming connected objects into one of eleven on-board drum-kit samples covering a variety of styles. The three clips trigger representative sonorities emulating snare or tom-tom drums, and hi-hat, ride, or crash cymbals; the single footswitch reproduces a bass-drum kick sound. Study 2 coupled the clip sensors to the steering-wheel, gear stick, driver’s left thigh, and placed a footswitch pedal on the driver’s left-foot floorboard. The volumes of each independent sensor and pedal were adjusted, equalized, and then reproduced via two external amplified speakers coupled to the output jack.

Fig. 1. CLIPHIT (Korg) Clip Drum Kit.
3.2. Procedure

The procedure used in Study 2 was the same as Study 1 (described above in Section 2.2). Drivers were required to drum-along to songs while engaged in a simulated driving task. It should be pointed out that drivers freely tapped-out the ‘steady pulse beat’, or reproduced the ‘rhythm of the melody’ line, or ‘improvised’ figures, syncopations, and drum fills. Although not requested to sing aloud, if drivers sang they were not cued to cease.

3.3. Music performance Analysis

MPA was implemented similarly to Study 1 (described above in Section 2.3), but with one exception: the unit of examination was set to the measure rather than the note resolution. A measure-by-measure resolution is all the more fitting when examining rhythmic figures as they require a wider temporal context that does not surface when analyzing note-by-note. The musicological evaluation was undertaken by an independent music expert who was both blind to the goals of the study, as well as to the context (i.e., simulated driving). The adjudicator was a 20-year-old professional brass player, with excellent relative-pitch hearing, 11 years of advanced music theory scholarship, 11 years of experience in chamber ensembles and orchestras.

3.4. Results

Initially, the aural examination of all sound files occupied roughly 4.5 h of listening time (336 min aural assessment) examining a total of 7980 measures. For each of the 84 recordings the adjudicator marked score-based errors on the music notation. Subsequently, the data of two participants with scores indicating ≥55% errors of rhythmic control already at both baseline performances were withheld from further analyses. This strategy was set in place to assure that findings of the study would reflect differences between driving conditions with the least amount of corruption by drivers who consistently tap off beat, who are incapable of reproducing a rhythmic figure, or who cannot replicate (i.e., track) a synchronous temporal pace. Such behavior might indicate a form of congenital amusia referred to as beat-deafness. First, coverage of performance (i.e., total number of measures performed) and the number of rhythmic errors (measure-by-measure) were calculated, and thereafter reconfigured as percentages. See Table 2A.

Then, percentages of coverage for percussive performances per measure by condition (with the baseline data averaged across both performances) were entered into a repeated-measures ANOVA. A highly statistically significant main effect surfaced: F(2,36) = 19.01, MSe = 135.27, p = 0.00001, η²p = 0.51. The effect size of this finding is a strong effect. Moreover, post-hoc Tukey tests comparing between the conditions found statistically significant differences: ND vs LD&HD: F(1,18) = 28.28, p = 0.00004, η²p = 0.61; LD vs HD: F(1,18) = 3.10, p = 0.09, η²p = 0.15. The effect size of the former finding is a strong effect, while the effect size of the latter finding is a medium effect. These results demonstrate that participants accompanied the music tracks by drumming for a far less percentage of the song when simulating driving tasks than when seated in a stationary parked vehicle, but that variances between the simulated driving conditions (LD versus HD) only approached statistical significance.

Finally, error percentages of percussive performances for ‘pulse beat’, ‘melodic rhythm’, and ‘improvised accompaniment’ per measure by condition (with the baseline data averaged across both performances) were entered into a repeated-measures ANOVA. No main effect surfaced: F(2,36) = 2.2336, MSe = 47.17, p = 0.12, η²p = 0.11. However, post-hoc Tukey tests comparing between the conditions demonstrated statistically significant variances: ND vs LD&HD: F(1,18) = 6.788, p = 0.02, η²p = 0.27. The effect size of this finding is a strong effect. Again, statistically significant differences between the two driving conditions did not surface: LD vs HD: F(1,18) = 0.0000, p = 0.99, η²p = 0.00. These results demonstrate that drivers erred most while drumming when driving as compared to when seated in a stationary parked vehicle. Moreover, the results indicate that highest level of errors occurred when the driver improvised an accompaniment. Namely, when drivers kept a steady pulse beat or tapped out the melodic rhythm, their performances were significantly better.

3.5. Discussion

Study 2 found that driver performances covered a less percent of the song when simulating a driving task than when seated in parked in a stationary vehicle. For the most part, drivers engaged in improvised percussion accompaniment to music background in the car. However, percussive performances were significantly more hampered when driving, and drivers erred the most when they improvised an accompaniment rather than when they tapped-out the melodic rhythm or simply kept a steady pulse beat.

4. General discussion and conclusions

Listening to music in the car will not be given up simply because it may place drivers more at risk. Cars are here to stay, and In-Car Music will forever be part of vehicular performance. Demonstrating the effects of music engagement to songs heard in the vehicle cabin is not only warranted because of the immense proportion of drivers who engage is such activities, but because the function and/or dysfunction of In-Car Music is still under debate. Although the current study did not
incorporate a task load index (such as NASA-TLX), finding that music performances became corrupted with decreased accuracy during driving might mean that drivers allocate greater mental resources to this secondary task than previously considered (by researchers of driver behavior, accident investigators, and the drivers themselves). The findings seem to point out that drivers do not (or perhaps cannot) withdraw altogether from music engagement in time of need for greater vehicular control. Namely, that when drivers are engaged in music activity, the primary driving task may simply be under-resourced. Future studies are certainly needed to investigate if obstructed music performances are the result of neglect or prioritization of the primary driving task.

The current study put in place a platform to assess music engagement as a secondary-task activity while driving. It was presumed that a musicological evaluation of vocal and percussive performances during simulated driving tasks would highlight aspects of driver-initiated music engagement, and the employment of MPA will assist traffic researchers in their strive to decode the utility of In-Car Music. Study 1 found MPA rather weak in differentiating between driving conditions regarding vocal intonation. As stated above, one possible limitation was the use of headphones. The use of headphones has been reported in many experimental laboratory-based simulator studies; Brodsky (2015) has been highly critical of these. While today we might consider donning headphones as highly unrealistic as far as driving contexts are concerned, drivers in the 1970s–1980s felt headphones to be highly fashionable. Nelson and Nilsson (1990) were the first (and perhaps only) research to test music exposure via fixed field headphones versus free field speakers in the automobile. They found “headphones [to be] a detriment in performance of a complex driving task that is dependent on auditory cues… it is likely that headphones sometimes hamper a motorist’s ability to respond to highway incidents” (p. 528) with increased RTs. Therefore, headphones might be viewed as a highly disadvantaged mode of exposure for simulator studies. But yet, as the current study did not log vehicle performance measures such as RTs etc., the use of headphones was deemed a valid method for the drivers to monitor both vehicle sounds and the music (background as well as their own voice) – all the while allowing for the audio recording of isolated vocal performances without vehicle sounds and background music accompaniment.

Nonetheless, MPA clearly pointed out that music engagement engenders capacity interference to far more of an extant than has been considered previously. For example, Study 1 demonstrated effects of driving conditions on significantly reduced memory recall for lyrics of highly popular and well-known songs. Study 2 found significant effects of driving on percussive performances involving accompanying rhythms and drumming sequences. One can only wonder if such effects surfaced from a relatively small sample using a PC-controlled video game emulating simulated driving, then, how much more hazardous might the interchange be when drivers actually sing-along to music in the real-world cross-town traffic road environments in which there is a more demanding driving scenario with on-coming traffic where drivers need to be alert all the time to avoid crashes. Future research studies might engage in this interesting question. The findings of Studies 1–2 clearly validate prima facie evidence for successful transfer of MPA from an arena of artistic performance targeting highly developed musical skill and expertise to a more ordinary traffic setting targeting everyday drivers without explicit music training. Unlike what has been published in the literature by Unal et al. (2012, 2013), the current study did not find that drivers disengaged altogether from secondary music activity or blocked-out aural backgrounds when they experienced higher demand simulated driving conditions. But rather, quite to the contrary, when they experienced higher demand simulated driving conditions they continued to engage with music; albeit, the music performances featured suboptimal characteristics such as decreased coverage of the song (as seen in gaps of the performance), and increased errors of motor control (timing inconsistencies maintaining pulse beat, inaccurate rhythm figures of the melody line, and improvised drumming accompaniment lacking temporal synchronization). Although one might hope that future studies might unravel the further issues about music engagement (most specifically if foiled music performances are the result of neglect or prioritization of the primary driving task), as far as the dispute regarding utility (namely the adaptive versus maladaptive nature of in-cabin music), the current study offers additional supplementary data from a different vantage supporting the view that In-Car Music causes driver distraction and inattention that can led to increased risk.

### Table 2

<table>
<thead>
<tr>
<th></th>
<th>Stationary no drive</th>
<th>Low-demand drive</th>
<th>High-demand drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Coverage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse Beat</td>
<td>32.8 (25.5)</td>
<td>29.3 (25.8)</td>
<td>25.0 (03.9)</td>
</tr>
<tr>
<td>Melodic Rhythm</td>
<td>12.8 (19.4)</td>
<td>12.4 (16.8)</td>
<td>17.9 (22.3)</td>
</tr>
<tr>
<td>Accompaniment</td>
<td>54.5 (28.8)</td>
<td>57.9 (32.5)</td>
<td>57.0 (29.3)</td>
</tr>
<tr>
<td>Total Coverage</td>
<td>91.5 (07.6)</td>
<td>74.8 (18.7)</td>
<td>69.1 (19.8)</td>
</tr>
<tr>
<td>(B) Errors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse Beat</td>
<td>5.0 (05.9)</td>
<td>6.1 (08.1)</td>
<td>4.8 (06.0)</td>
</tr>
<tr>
<td>Melodic Rhythm</td>
<td>3.2 (04.0)</td>
<td>4.3 (04.5)</td>
<td>6.4 (09.0)</td>
</tr>
<tr>
<td>Accompaniment</td>
<td>21.4 (18.5)</td>
<td>23.8 (19.6)</td>
<td>22.6 (18.5)</td>
</tr>
<tr>
<td>Total Errors</td>
<td>29.7 (16.7)</td>
<td>33.8 (18.3)</td>
<td>33.7 (18.2)</td>
</tr>
</tbody>
</table>

* = Mean percentage of performance errors.
As an afterthought, and when looking at the future, we seem to be welcoming the automated iCar. These vehicles are discussed more often and commonly found in the forefront of scientific presentations that seemingly focus on driver behavior, vehicular control, and traffic engineering. The iCar will no doubt allow the traveler inhabitant, who was referred to yester-year as the driver, to be otherwise engaged in a host of secondary tasks. Some time ago, Damiani, Deregibus, and Andreone (2009) foresaw that...

Men and women of the future when moving will continue their normal life, leisure, and work while the car will take care of their safety... Car “inhabitants” will entertain themselves and communicate with the world outside, all useful and interesting information will flow fluently to the driver without distracting him/her from the primary driving task…” (p. 95).

Perhaps the most popular form of leisure entertainment that drivers will immerse themselves in while inhabiting the automobile is music. As if performing themselves, drivers will sing melodies aloud, vocalize background fills and runs, finger solos in an air-guitar fashion, pound-out drum kicks and syncopated rhythms, and even dance. However, when considering that drivers do not necessarily disengage from music activity or block-out aural backgrounds altogether when experiencing higher traffic demands, future research efforts must investigate In-Car Music. In this connection, music engagement must be further explored because such activity may indeed generate an increased time window required to take-over vehicle control, and this interval may in fact be far beyond the current industry standard benchmark for ‘time to get back in the loop’, which is set at 7s (Gold, Damböck, Lorenz, & Bengler, 2013). The reality may just be that drivers who engage in music activity would find themselves hopeless at disengaging and taking-over within such a timespan. Moreover, we might unfortunately have to consider the fact that, in-cabin music exposure from automotive high-end music reproduction systems employing digital theatre-type sound with a multi-channel surround-sound system cabled to as many as fourteen speakers placed strategically throughout the vehicle cabin, may simply eclipse any auditory hazard signal beckoning a 7-s warning alert to take control over the vehicle because of an imminent threat.

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References


Walsh, M. J. (2010). Driving to the beat of the one’s own hum: Automobility and musical listening. Studies In Symbolic Interaction, 35, 201–221.