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Psychological, psychophysiological and behavioural effects of participant-selected vs. researcher-selected music in simulated urban driving

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ABSTRACT

We investigated the effect of participant-selected (PSel) and researcher-selected (RSel) music on urban driving behaviour in young men ($N = 27$; $M_{age} = 20.6$ years, $SD = 1.9$ years). A counterbalanced, within-subjects design was used with four simulated driving conditions: PSel fast-tempo music, PSel slow-tempo music, RSel music and an urban traffic-noise control. The between-subjects variable of personality (introverts vs. extroverts) was explored. The presence of PSel slow-tempo music and RSel music optimised affective valence and arousal for urban driving. NASA Task Load Index scores indicated that the urban traffic-noise control increased mental demand compared to PSel slow-tempo music. In the PSel slow-tempo condition, less use was made of the brake pedal. When compared to extroverts, introverts recorded lower mean speed and attracted lower risk ratings under PSel slow-tempo music. The utility of PSel slow-tempo and RSel music was demonstrated in terms of optimising affective state for simulated urban driving.

1. Introduction

Driver psychology has been identified as a central factor in the causation of road accidents (Brodsky, 2015; Parnell et al., 2020). Younger road users are the most prone to fatalities and casualties, although overall road safety appears to improve through the lifespan, with some reduction evident in later life (DfT, 2020; World Health Organization, 2020). In our digital age, in which streamed music has become *de rigueur*, vehicular music listening has been identified as an activity that has a bearing on the emotions and performance of drivers (Brodsky, 2015, 2018).

It is estimated that around 95% of drivers listen to music in-car (Brodsky and Kizner, 2012) and it is in this context that 91% of their musical exposure occurs (Sloboda et al., 2001). People's vehicular music-listening habits are of seminal importance because safety-relevant driving behaviours are related to the psychological and psychophysiological effects of music (Brodsky and Slor, 2013; Millet et al., 2019; Wiesenthal et al., 2003). Music listening in combination with the intensity and fidelity of sound are germane to the driving experience of many young men (Pècher et al., 2009). The use of music – regardless of its style – is linked with road accidents and fatalities due to its arousing and distractive qualities (FakhrHosseini and Jeon, 2019; Royal, 2003). The central issue from a safety perspective is not the use of music per se but rather *how* it is used, and how it bears influence on a driver's emotional state (Brodsky and Kizner, 2012).

Previous research has highlighted both positive and negative consequences of music-induced emotions and psychophysiological states in terms of driving behaviour (e.g., calmness vs. inattentiveness; see Navarro et al., 2018, 2019; Wen et al., 2019). Music listening has also been shown to influence a range of perceptual, attentional and cognitive processes (Millet et al., 2019; Poikonen et al., 2016). A deeper comprehension of such processes in younger drivers will have manifold

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implications for road safety (Brodsky and Slor, 2013). Such understanding could also facilitate harnessing of in-vehicle music listening to optimise driving performance.

Past research, predicated on real-world data from the US, assigned 94% of the critical reasons for crashes to the behaviour of drivers (Singh, 2015). The critical reason is defined by Singh (2015, p. 1) as "… the immediate reason for the critical pre-crash event and is often the last failure in the causal chain of events leading up to the crash." A recent meta-analysis showed that music listening has a detrimental effect on longitudinal vehicle control ($z = -2.36$, $p = .02$) and collisions ($z = -2.78$, $p = .01$; Millet et al., 2019). Thus, the presence of in-vehicle music has been implicated as one of the factors in the causal chain of events leading to an accident (Royal, 2003).

An important parameter to take into consideration is whether drivers have a choice (i.e., agency) in terms of the music they listen to (Ünal et al., 2013). In past work, driver miscalculations, inaccuracies and violations were observed more frequently with driver-preferred music than with music designed to improve driving safety and performance (Brodsky and Slor, 2013). Similarly, driver-preferred music was more positively assessed for awareness of the aural environment than experimenter-designed background music; the latter being oriented towards improving driver safety (Brodsky and Kizner, 2012). Little research attention has been devoted to matching music programmes to the driver and their specific driving task, despite the potential of this stimulus to make a positive contribution to the safety issues that surround young drivers – particularly males.

The extensive driver distraction literature sheds light on how different types of passive (e.g., music listening) and active (e.g., tuning the radio) activities influence driver responses and decision-making (see Regan et al., 2013). A driving simulator study found that mental effort was increased by music parameters such as the presence of intelligible lyrics, high sound intensity, the complexity of the rhythm and fast tempi (Ünal et al., 2012). Lyrics are especially distracting, as the linguistic element causes active, syntactic processing supported by specific neural mechanisms (see Chien and Chan, 2015; Sanchez et al., 2014).

Previous studies have revealed that distraction or inattention is a factor in nearly 80% of road traffic accidents (Klauer et al., 2006; Olson et al., 2009). From an information processing perspective (e.g., Consiglio et al., 2006; Ho et al., 2007), additional input such as music could negatively affect performance if the attentional demands exceed the driver's capacity to respond (e.g., in response to unexpected events). It is relevant to consider sex, age and personality because these factors are germane to musical responsiveness and influence road safety (Arnett, 1991; Liu et al., 2013; Oltedal et al., 2006). Moreover, sensation seeking, which is associated with extroverts, high levels of testosterone and a need for peer approval (satisfied by risk-taking behaviour), appears to go hand-in-hand with loud, low-frequency, beat-heavy music (e.g., gangster rap and drill). The consequences of this association can be catastrophic (Arnett, 1991).

There has been a lineage of work assessing the relationship between personality and driving behaviour, albeit the moderating influence of music have not been subject to extensive experimental work (Millet et al., 2019). There is a tendency for extroverts to benefit more than introverts from the stimulation offered by music (e.g., in reaction time tasks; Fagerström and Lisper, 1977). A questionnaire-based study found that personality traits, such as anger, sensation-seeking, altruism and normlessness, were effective predictors of driving violations (Yang et al., 2013). A similar study showed that risky driving behaviour and crashes were significantly correlated with excitement-seeking – a tendency commonly exhibited by extroverts (Oltedal et al., 2006).

A driver's blink rate is an objective marker of both mental and visual workload (Recarte et al., 2008) that illustrates to what extent the driving task, considered to be predominantly visual (Ho and Spence, 2009; Sivak, 1996), is demanding. Specifically, blink disinhibition for higher mental workload and blink inhibition for higher visual demand (Recarte et al., 2008). Another objective indicator of mental load is heart rate variability (HRV). This is a non-invasive electrocardiographic measure that reflects the activity of the sympathetic and vagal components of the autonomic nervous system on the heart's sinus node (Sztajzel, 2004). A reduction in variability is indicative of higher mental load.

1.1. *A theory-based rationale for the present study*

The present study is centred on Millet et al.'s (2019) conceptual model for the effect of music on vehicular performance. The model posits key factors that moderate the relationship between driving performance and music listening: (a) music listening as an independent variable; (b) potential theoretical mediators including psychological (e.g., arousal, emotion and perceived workload) and/or physiological response (e.g., heart rate, blinks); (c) vehicular performance as an outcome (e.g., response times in hazardous situations, vehicle control, compliance with the highway code); and (d) moderator variables that include music features (e.g., tempo), driver characteristics (e.g., personality) and other contextual factors (e.g., road type).

Fuller's Driver Control Theory (2011) is an adjunct theory that is also relevant to the present study, given that it highlights the interplay of task demand, driver capability and music. Fuller's model postulates that drivers adjust their behaviour based on their perceived capability to match the demands of the driving situation. These demands might be affected by perceptual input, driving conditions, perceived task difficulty, the behaviour of other drivers, experience and emotional information. As perceptual processes and control actions have limitations, drivers are continuously creating and maintaining conditions for driving within such limitations. Drivers need to ensure that their capabilities exceed the demands of the driving task to prevent loss of control. Young and inexperienced male drivers struggle to maintain the superiority of their capabilities over task demands, as they are more influenced by sensation seeking and exhibit greater intention to speed than any other subgroup (Cestac et al., 2011; Clarke et al., 2005).

The present study explores the influence of music as a moderator of behaviour and performance in the context of Fuller's model using a wide range of measures. Music could support safety-relevant behaviours in challenging and complex driving situations (e.g., dense urban traffic; Brodsky, 2015). Such situations are demanding in terms of perceptual and processing load, and music could help young drivers in preserving a balance between the demands and their capabilities. The researcher-selected music employed in the present study had a tempo range (90–110 bpm) and psycho-acoustic properties (e.g., resonance and entrainment) deemed optimal for the task of urban driving.

1.2. *Aims and hypotheses*

The central purpose of this study was to evaluate urban driving behaviour among young males in response to four forms of auditory input: Self-selected stimulative music, self-selected calming music, researcher-selected music that is deemed suitable for the driving task *and* individual based upon their personal characteristics/preferences, and an urban traffic-noise control. Matching the music to the driver and the task could, in theory, optimise psychomotor arousal, attentional capacity (e.g., blinks and HRV) and driving performance. Such matching pertains to the "music listening as an independent variable" factor of Millet et al.'s (2019) model (see Fig. 1). This model will be tested, as music may have an influence on the degree to which drivers adapt their driving behaviour to increase the likelihood that task demands are within their capabilities. For example, musical parameters such as tempo may help drivers in unconsciously regulating haemodynamic variables (e.g., HRV) while driving in a dense, urban environment that they ordinarily find stressful.

We hypothesised that: participant self-selected (PSel) slow-tempo music and researcher-selected (RSel) music conditions would engender the best affective state for simulated urban driving (i.e., positive affective valence coupled with moderate levels of affective arousal)

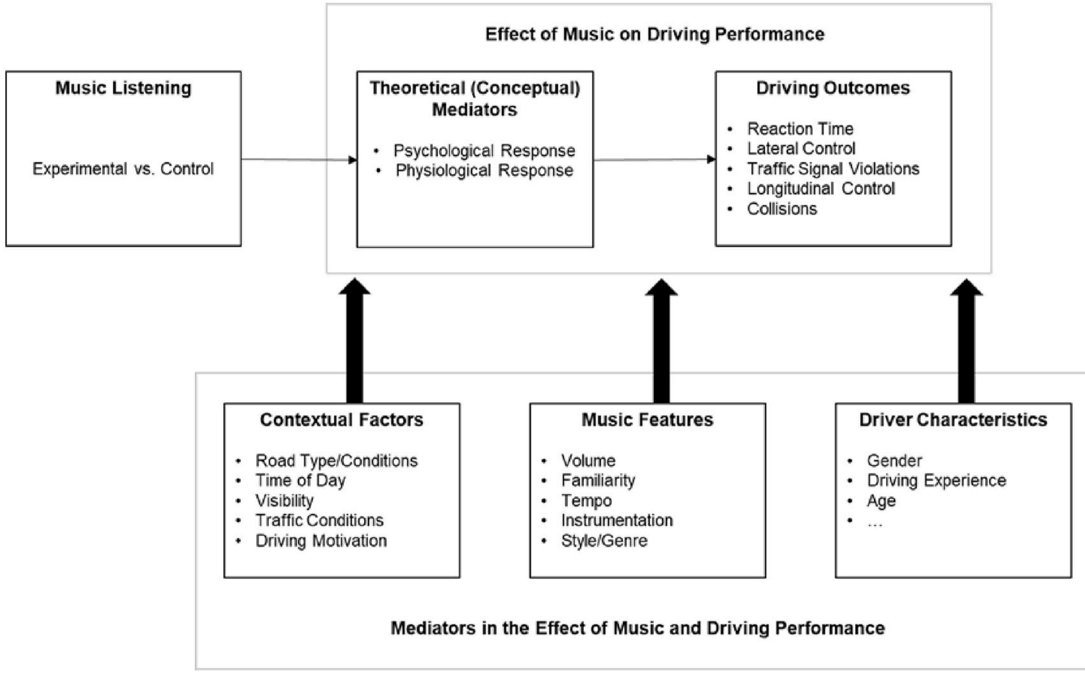

Fig. 1. Millet et al.'s (2019) process model for the effect of music on vehicular performance. "The impact of music on vehicular performance: A meta-analysis", by B. Millet, A. Soyeon, and J. Chattah, 2019, Transportation Research Part F, 60, p. 756 (https://doi.org/10.1016/j.trf.2018.10.007). Copyright 2018 by Elsevier. Reprinted with permission.

when compared to PSel fast-tempo and urban traffic-noise control (H_1); PSel slow-tempo and RSel music conditions would lead to the lowest scores on the Rating Scale Mental Effort (RSME) and NASA Task Load Index (TLX) items (H_2); PSel fast-tempo music would elicit higher blink frequency, subjective mental workload (i.e., measured using the NASA-TLX) and heart rate (HR; H_3); PSel slow-tempo music and RSel music would positively influence driving behaviour, including risk ratings, task duration (i.e., through observation of the speed limit) and use of accelerator/brake pedals (H_4). A number of exploratory analyses were conducted under the null hypothesis (H_5); these entailed the influence of experimental conditions on HRV and how personality was associated with the range of dependent variables.

2. Methods

2.1. Power analysis

A power analysis was conducted using G*Power3 (Faul et al., 2009) to estimate an appropriate sample size. We applied the "Cohen (1988)" effect size option and inputted an effect size derived from the Brodsky and Kizner (2012) study on the optimisation of in-car music for safe driving. Specifically, the effect size was derived from averaging the effect sizes pertaining to positive and negative affect in the Brodsky and Kizner study. Accordingly, with an effect size of $\eta_p^2 = .34$, an alpha level of 0.05, and power at .8 to protect beta at four times the level of alpha, the analysis indicated that 24 participants would be required. An additional three participants were recruited to protect the study against experimental dropout and deletions due to outliers.

2.2. Participants

Volunteer participants comprised of a convenience sample of 27 young, adult males ($M_{age} = 20.6$ years, $SD = 1.9$ years), all of whom provided informed written consent. They were recruited through word-of-mouth, promotional flyers, posters and social media posts at Coventry University, UK as well as in the surrounding areas. Ethical approval was obtained from the ethics committees of Brunel University London, UK and Coventry University, UK. Participants had to meet five inclusion criteria: (a) be in the age range 18–25 years; (b) report good general health; (c) report a lack of motion-sickness susceptibility when playing immersive video games or as a road passenger; (d) no hearing deficiency and/or visual impairment; and (e) hold a UK driver's licence.

2.3. Music selection procedure

Several steps were taken to ensure standardisation in terms of the familiarity and psycho-acoustic properties of the music tracks used across the three experimental conditions. First, the research team established participants' preferred radio stations during driving using an online survey that was administered in advance of their visit to the driving simulator room. Second, the research team listened to published playlists from participants' preferred radio stations (each participant provided three) and established 6–7 tracks from each radio station that fell into the tempo range 130–140 bpm (for the participant-selected fast-tempo condition) and 60–70 bpm (for the participant-selected slow-tempo condition) that were not highly syncopated, and devoid of explicit lyrics. Participants selected three tracks from a list provided to them; the contents of the list represented their preferred radio stations. Third, for the experimenter-selected music, the research team selected three tracks they deemed to fall into the bottom-right quadrant of Russell's (1989) Circumplex Model of Affect (i.e., tracks that were pleasurable and calming) but did not replicate tracks selected by the participants (*Lovely Day* by Bill Withers [98 bpm], *Señorita* by Shawn Mendes and Camila Cabello [95 bpm], and *These Days* by Rudimental feat. Jess Glynne, Macklemore, and Dan Caplen [93 bpm]).

2.4. Psychological measures

A range of psychological measures was administered to assess subjective mental workload, core affect and personality traits. To measure perceived mental workload, we employed a unidimensional tool, the Rating Scale Mental Effort (RSME; Zijlstra, 1993) and a multidimensional, six-item instrument, the NASA Task Load Index (NASA-TLX; Hart and Staveland, 1988). To measure core affect after each trial, we administered the Affect Grid (AG; Russell et al., 1989); a single-item instrument used to assess affect along the dimensions of pleasure–displeasure (relating to affective valence) and arousal–sleepiness (relating to affective arousal). To measure personality, we used the Big Five Inventory (BFI; John and Srivastava, 1999), which is a relatively brief, self-report inventory designed to measure the Big Five personality dimensions (i.e., extroversion, agreeableness, conscientiousness, neuroticism and openness). Full details for each of these measures can be found in Supplementary Material 1.

2.5. Experimental procedures

A few days before the experiment, each participant completed a set of online questionnaires (inc. informed consent, demographic items, idiographic items [e.g., to establish their favourite radio stations while driving]). The participant was required to visit the simulator room on one occasion and each set of trials (i.e., the entire experiment) lasted 90–120 min. At the start of their session, baseline measures of HRV were taken and the participant was habituated to the driving simulator. They were also administered ginger confectionery (nut free), as it has been indicated that ginger functions as a mild antidote to motion sickness (Lien et al., 2003). The participant was then led on a 10-min walk around the university campus as a refresher in advance of the experimental phase, which entailed three experimental conditions and a control condition. A within-subjects design was adopted and assignment to conditions was counterbalanced. The full experimental procedure timeline is displayed in Fig. 2.

A high-grade, fixed-based driving simulator was used that consisted of a car buck and a three-channel HD projection system. The latter provided a full panoramic view on a 220° curved projection screen and seamless output with 5760 × 1080-px display (60 Hz res.). A 32″ LED HD screen was mounted at the rear of the buck to simulate the rear-view mirror, whereas wing mirrors had integrated 10″ SVGA resolution LCD screens. The simulation environment was created by use of OpenDS 4.0 software and the speedometer was displayed on the projection screen. The buck was fitted with two bass shakers and the steering wheel equipped with a force feedback steering control unit. The shakers converted audio signals from an amplifier into physical vibrations that participants felt through the buck frame. The music was administered by use of two 16 W wireless speakers (JBL Flip Essential Portable) positioned at the rear of the buck, to the left and right for a stereo effect.

Participants completed an 8-min urban driving simulation under four conditions: PSel fast music, PSel slow music, RSel music and an urban traffic-noise control at the same sound intensity as the experimental conditions. We used a decibel meter app (Decibel – Sound Level Meter, MWM; Boulogne-Billancourt, France) to delimit all study conditions to a sound intensity of 70 dBA, which is entirely safe from an audiological standpoint (Lindgren and Axelsson, 1988). Each condition was separated by a 5-min break, during which participants were administered a 2-min filler task (a wordsearch) to negate any potential carryover effects. To enhance ecological validity, the simulation included a number of randomly presented events, such as changing traffic lights, vehicles cutting in at junctions and slow-moving vehicles that had the potential to prompt risk-taking behaviour (e.g., inappropriate overtaking).

Perceived mental load, core affect, psychophysiological responses and driving behaviour were measured on the immediate conclusion of each simulator-based trial. Added to the within-subjects factor (condition), was the between-subjects factor of personality (introverts vs. extroverts). To increase the cognitive demand of the urban simulation in an ecologically valid way, the participant was played a singular traffic announcement in each trial that they were required to repeat aloud. They were asked to maintain a speed of 30 mph and the simulation was populated with traffic in both directions to maintain ecological validity. The participant was instructed to observe all traffic signals/road signs in accord with the UK Highway Code.

The driving simulator was equipped with an automatic transmission system and so the participant was told not to use the gear lever – only the steering wheel, accelerator pedal and brake pedal. Moreover, to use the rear-view and side-view mirrors, as they would do on the road. The participant was also instructed to have adequate sleep the night before testing, avoid alcohol consumption and refrain from ingesting caffeine on the day of their visit. Room temperature and lighting conditions were standardised throughout the experiment: Temperature was maintained at 21 °C and the lighting emanated from the simulator's curved screen. There were blackout curtains just behind the buck, and room lights were turned off during experimental trials.

2.6. Heart rate variability

HRV data were recorded throughout each trial by use of a Polar H10 (Kempele, Finland) heart rate monitor, fitted around the chest with the monitor just beneath the sternum. Data were imported into Kubios HRV Standard (v3.4.3) software (https://www.kubios.com) wherein the

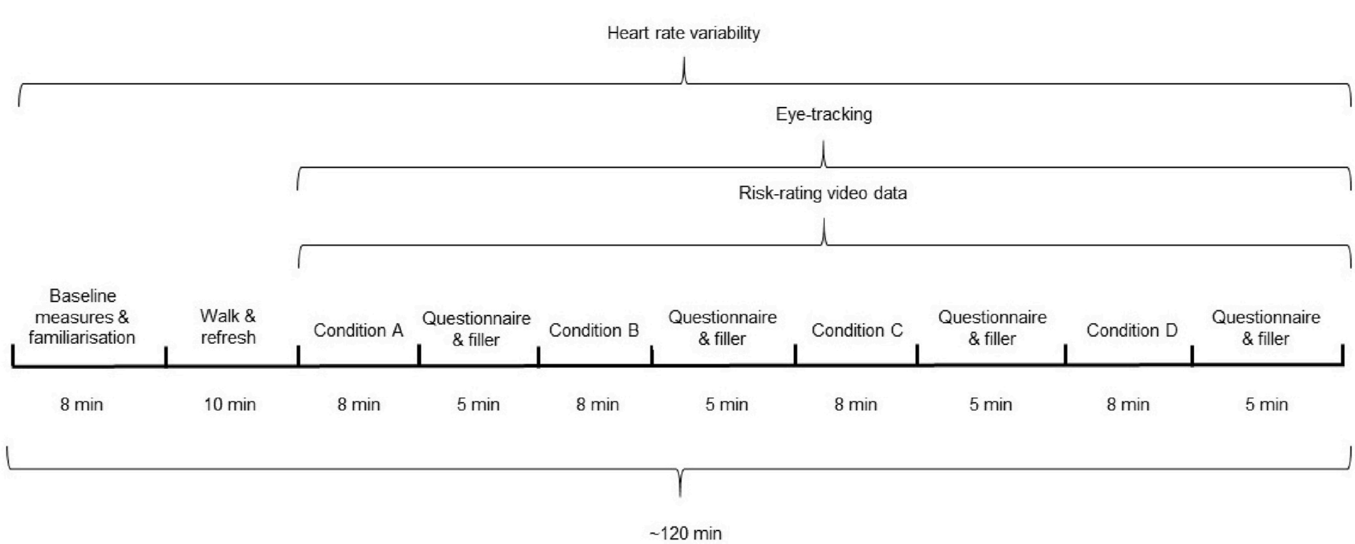

Fig. 2. Experimental procedure timeline.

signal was broken down into four samples, each lasting 5 min. Two time-domain indices were extracted from the cardiac electrical signal. Standard deviation of normal-to-normal RR intervals (SDNN) was used as an index of global activity of the sympathetic–parasympathetic system and root mean square of successive RR interval differences (RMSSD) was used as an index of parasympathetic activity (Acharya et al., 2006).

2.7. Eye-tracking

The Smart Eye Pro eye-tracking system (Gothenburg, Sweden) was used to record the number of blinks throughout each trial (converted to blinks per min), as an objective index of mental workload. It consists of 3 × 1.3 MP IP cameras, mounted on the driving buck frame. The system was calibrated for each participant's gaze and data were captured at a sampling rate of 60 Hz.

2.8. Data analysis

Checks for univariate outliers were conducted using standardised scores ($z > \pm 3.29$) and for multivariate outliers using the Mahalanobis distance test ($p < .001$; Tabachnick and Fidell, 2019). Parametric assumptions that underlie within-subjects ANOVA (Tabachnick and Fidell, 2019) were assessed (e.g., Q–Q plots and the Shapiro–Wilk test for normality). Initial analyses for the psychological measures (i.e., RSME, NASA-TLX and Affect Grid) were conducted using mixed-model Condition × Personality (M)ANOVAs and significant *F* tests were followed up with pairwise/multiple comparisons. Where the assumption of sphericity was violated, Greenhouse–Geisser-adjusted *F* tests were used.

Three types of behavioural data were acquired from the simulation: (a) a risk-rating (on the scale from 1 [*safe driving*] to 4 [*reckless driving*]) derived from video data (without audible sound) and pertaining to driving performance in the entire trial. Three members of the research team conducted the ratings and inter-rater reliabilities were computed using intra-class correlations (ICCs); (b) course completion time (min); (c) mean speed (mph) and (d) accelerator and brake pedal positions (i.e., 0 = no pressure applied, 1 = maximum braking). Where parametric assumptions were not met, data were analysed by means of rank-based, nonparametric tests using the nparLD package (Noguchi et al., 2012) of data analysis software R.

3. Results

No univariate or multivariate outliers were identified. Examination of Q–Q plots of the distributional properties of interval and ratio data in each cell of the analysis revealed minor violations for the RSME, NASA-TLX and Affect Grid variables, hence they were analysed using parametric ANOVAs. From analysis of BFI scores, 11 participants were classified as introverts ($M_{\text{extroversion score}} < 3.5$; i.e., did not endorse extroversion in response to items presented on a 1 [*disagree strongly*] to 5 [*agree strongly*] Likert scale) and 16 participants were classified as extroverts ($M_{\text{extroversion score}} \geq 3.5$; also see Supplementary Material 2). Statistically significant differences (at $p < .05$) did not emerge between introverts and extroverts in terms age, years of driving and lifetime mileage (see Supplementary Material 2).

Box's test for equivalence of covariance matrices was used to assess variance differences between the introvert and extrovert groups, and did not show any violations. Hence, mixed-model analyses for these variables were conducted using parametric ANOVAs. All behavioural data recorded from the simulator violated assumptions of normality and were thus analysed by use of nonparametric, rank-based ANOVAs. Descriptive statistics for all variables are presented in Table 1.

3.1. Core affect

The mixed-model MANOVA for core affect indicated no significant two-way interaction of Condition × Personality ($\eta_p^2 = .00$), but there was a main effect of condition ($\eta_p^2 = .57$; see Table 2), associated with a large effect size. Step-down *F* tests showed significant effects for both affective valence and arousal (see Fig. 3). For the former, pairwise comparisons indicated differences between three experimental conditions and the urban traffic-noise control. For the latter, there were differences between the PSel fast-tempo condition and both the PSel slow-tempo and RSel music conditions; the PSel slow and RSel conditions elicited the highest affective arousal scores. There were also differences between the control and both the PSel slow-tempo and RSel music conditions, with control eliciting the highest scores.

Table 1
Descriptive statistics across conditions for dependent variables.

Music condition	PSel fast tempo		PSel slow tempo		RSel		Urban traffic control	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Affect Grid								
Affective arousal	6.56	1.72	4.22	2.14	4.33	1.84	6.00	2.08
Affective valence	6.70	1.61	7.22	1.31	6.96	1.37	3.85	1.99
Rating Scale Mental Effort	46.30	28.84	46.30	22.73	41.11	22.76	44.44	23.26
NASA-TLX								
Mental demand	7.22	4.70	6.96	4.12	6.89	3.59	8.81	4.89
Physical demand	3.63	2.44	4.33	3.48	4.67	3.79	4.59	3.48
Temporal demand	4.44	2.98	4.56	2.94	4.93	3.21	5.93	3.53
Performance	6.00	4.10	5.56	3.76	6.11	3.74	5.78	3.68
Effort	7.52	4.59	8.15	4.98	7.11	4.43	8.22	5.63
Frustration	4.74	3.73	3.85	2.64	5.11	3.68	6.22	4.71
Eye blinks (per min)	12.59	5.81	12.90	5.73	13.61	5.96	11.98	5.77
Cardiac variables								
Mean heart rate (bpm)	77.56	9.46	77.11	10.32	77.59	12.44	77.37	9.84
HRV SDNN	49.59	19.42	47.70	16.94	49.24	16.70	46.34	16.14
HRV RMSSD	46.56	23.11	45.24	19.81	46.45	18.94	43.39	20.48
Driving behaviour								
Task duration (s)	455.21	7.34	458.67	11.24	455.48	7.59	455.69	7.18
Mean speed (mph)	23.93	2.55	23.80	2.92	24.02	2.61	23.76	2.69
Acceleration	0.33	0.00	0.33	0.002	0.33	0.003	0.33	0.004
Braking	0.0006	0.0001	0.0004	0.0001	0.0007	0.0001	0.0008	0.0002
Risk rating	1.65	0.83	1.64	0.86	1.78	0.80	1.70	0.76

Note. PSel = participant selected; RSel = researcher selected; NASA-TLX = NASA Task Load Index; bpm = beats per minute; HRV = heart rate variability; SDNN = standard deviation of the NN intervals; RMSSD = root mean square of the successive differences; mph = miles per hour.

Table 2
Inferential statistics of within-subjects (M)ANCOVA analyses.

	Pillai's Trace	*F*	*df*	*p*	η_p^2
Core Affect[a]					
Music Condition × Personality	.044	0.14	6, 20	.983	.04
Music Condition	.807	13.94	6, 20	.000	.81
Personality	.134	1.85	2, 24	.179	.13
Affective Valence[b]					
Music Condition × Personality	–	0.11	3, 75	.955	.00
Music Condition	–	33.58	3, 75	.000	.57
Personality	–	3.79	1, 25	.063	.13
Affective Arousal[b]					
Music Condition × Personality	–	0.21	3, 75	.866	.00
Music Condition	–	10.89	3, 75	.000	.30
Personality	–	0.08	1, 25	.786	.00
Rating Scale Mental Effort					
Music Condition × Personality	–	0.98	3, 75	.422	.02
Music Condition	–	0.65	3, 75	.588	.04
Personality	–	0.97	1, 25	.350	.04
NASA-TLX Mental Demand					
Music Condition × Personality	–	1.07	3, 75	.366	.04
Music Condition	–	3.05	3, 75	.036	.11
Personality	–	0.01	1, 25	.919	.00
NASA-TLX Physical Demand					
Music Condition × Personality	–	0.07	3, 75	.973	.00
Music Condition	–	1.79	3, 75	.157	.07
Personality	–	0.63	1, 25	.445	.02
NASA-TLX Temporal Demand					
Music Condition × Personality	–	1.43	3, 75	.240	.05
Music Condition	–	2.46	3, 75	.070	.09
Personality	–	1.94	1, 25	.175	.07
NASA-TLX Performance					
Music Condition × Personality	–	0.06	3, 75	.980	.00
Music Condition	–	0.39	3, 75	.805	.01
Personality	–	0.25	1, 25	.621	.01
NASA-TLX Effort					
Music Condition × Personality	–	0.34	3, 75	.793	.01
Music Condition	–	0.75	3, 75	.523	.06
Personality	–	0.03	1, 25	.859	.00
NASA-TLX Frustration					
Music Condition × Personality	–	0.98	3, 75	.563	.04
Music Condition	–	4.35	3, 75	.007	.15
Personality	–	1.82	1, 25	.188	.07
Mean heart rate					
Music Condition × Personality	–	0.86	3, 75	.484	.03
Music Condition	–	0.13	3, 25	.944	.00
Personality	–	0.11	1, 25	.742	.00
RMSSD					
Music Condition × Personality	–	0.86	3, 75	.484	.03
Music Condition	–	0.35	3, 75	.784	.02
Personality	–	0.29	1, 25	.637	.00
SDNN					
Music Condition × Personality	–	0.16	3, 75	.922	.00
Music Condition	–	0.49	3, 75	.685	.02
Personality	–	0.03	1, 25	.868	.00
Blink rate					
Music Condition × Personality	–	0.39	3, 66	.763	.12
Music Condition	–	1.02	3, 66	.390	.04
Personality	–	3.11	1, 22	.092	.39
Task Duration[c]					
Music Condition × Personality	–	4.81	3, 75	.002	.16
Music Condition		0.25	3, 75	.702	.01
Personality		0.27	1, 25	.608	.01
Mean Speed[c]					
Music Condition × Personality	–	2.83	3, 75	.034	.13
Music Condition	–	0.26	3, 75	.614	.03
Personality	–	0.25	1, 25	.845	.02
Acceleration[c]					
Music Condition × Personality	–	0.70	3, 75	.533	.04

(*continued on next page*)

Table 2 (*continued*)

	Pillai's Trace	F	df	p	η_p^2
Music Condition	–	0.08	3, 75	.953	.00
Personality	–	0.43	1, 25	.508	.01
Braking[c]					
Music Condition × Personality	–	0.22	3, 75	.861	.02
Music Condition	–	2.84	3, 75	.041	.14
Personality	–	0.22	1, 25	.862	.01
Risk Taking[c]					
Music Condition × Personality	–	2.82	3, 75	.043	13
Music Condition	–	0.89	3, 75	.419	.01
Personality	–	0.92	1, 25	.329	.03

Note. NASA-TLX = NASA Task Load Index; RMSSD = root mean square of successive RR interval differences; SDNN = standard deviation of NN intervals. [a]MANCOVA for core affect, with affective valence and affective arousal as dependent variables. [b]Step-down ANOVAs for the affective valence and affective arousal dimensions of the Affect Grid. [c]Nonparametric rank-based factorial analyses. F values represent ANOVA-Type Statistic (ATS).

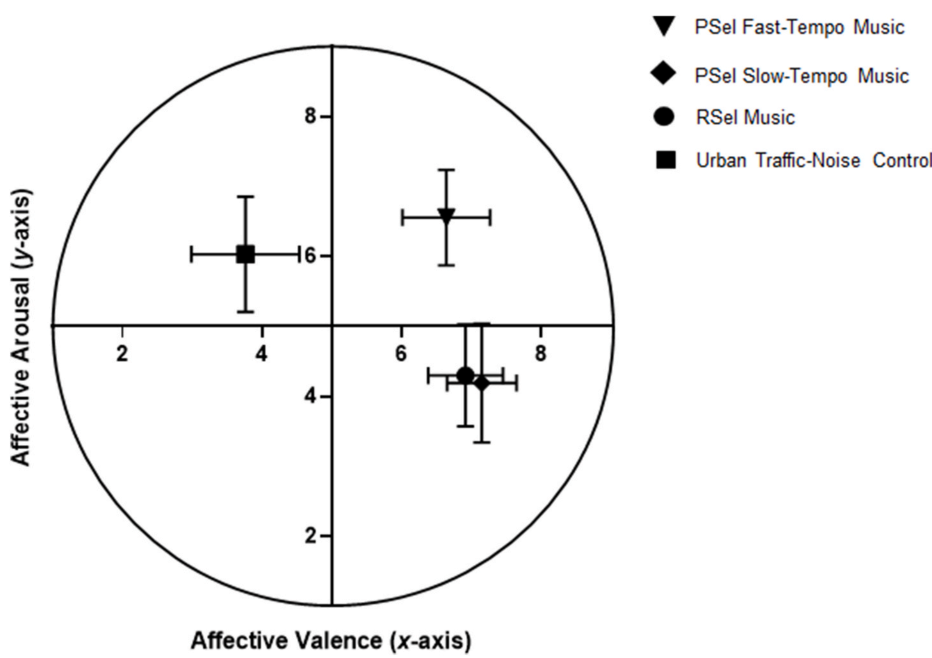

Fig. 3. The main effect of condition for core affect ($p < .001$). *Note.* Error bars represent 95% confidence intervals.

3.2. Mental effort

The mixed-model ANOVA for RSME indicated no significant interaction ($\eta_p^2 = .04$) or main effects ($\eta_p^2 = .03$; see Table 2). The mixed-model MANOVA for the six NASA-TLX items indicated no two-way interaction ($\eta_p^2 = .09$), but there was a significant main effect of condition ($\eta_p^2 = .14$; see Table 2), associated with a large effect size. Step-down F tests showed significant effects for the mental demand and frustration items (see Fig. 4). For the latter, pairwise comparisons did not reveal any differences, but for the former, differences emerged between PSel slow-tempo music and control, wherein the control yielded the highest scores.

3.3. Eye blinks per minute

The mixed-model ANOVA for eye blinks per min indicated no significant interaction ($\eta_p^2 = .02$) or main effect of condition ($\eta_p^2 = .04$). The main effect of personality was marginally nonsignificant but associated with a medium effect size ($\eta_p^2 = .12$).

3.4. Cardiac variables

A 4 (Condition) × 2 (Personality) ANOVA for mean HR did not reveal a significant interaction or any main effects (see Table 2). A 4 (Condition) × 2 (Personality) MANOVA for the HRV variables of SDNN and RMSSD, rank-based factorial analyses did not show any significant interactions or main effects (see Table 2).

3.5. Driving behaviour

The nonparametric mixed-model ANOVA for task duration showed no main effect but there was a significant Condition × Personality interaction ($\eta_p^2 = .18$), associated with a large effect size. Examination of 95% CIs indicated that introverts under the PSel slow-tempo condition took more time to complete the simulation than extroverts. Similarly, there was no main effect of condition for mean speed, but a significant Condition × Personality interaction emerged ($\eta_p^2 = .13$; see Fig. 5a), associated with a medium-to-large effect size. Examination of 95% CIs indicated that introverts recorded lower mean speed under the PSel slow-tempo condition compared to the other three conditions, while

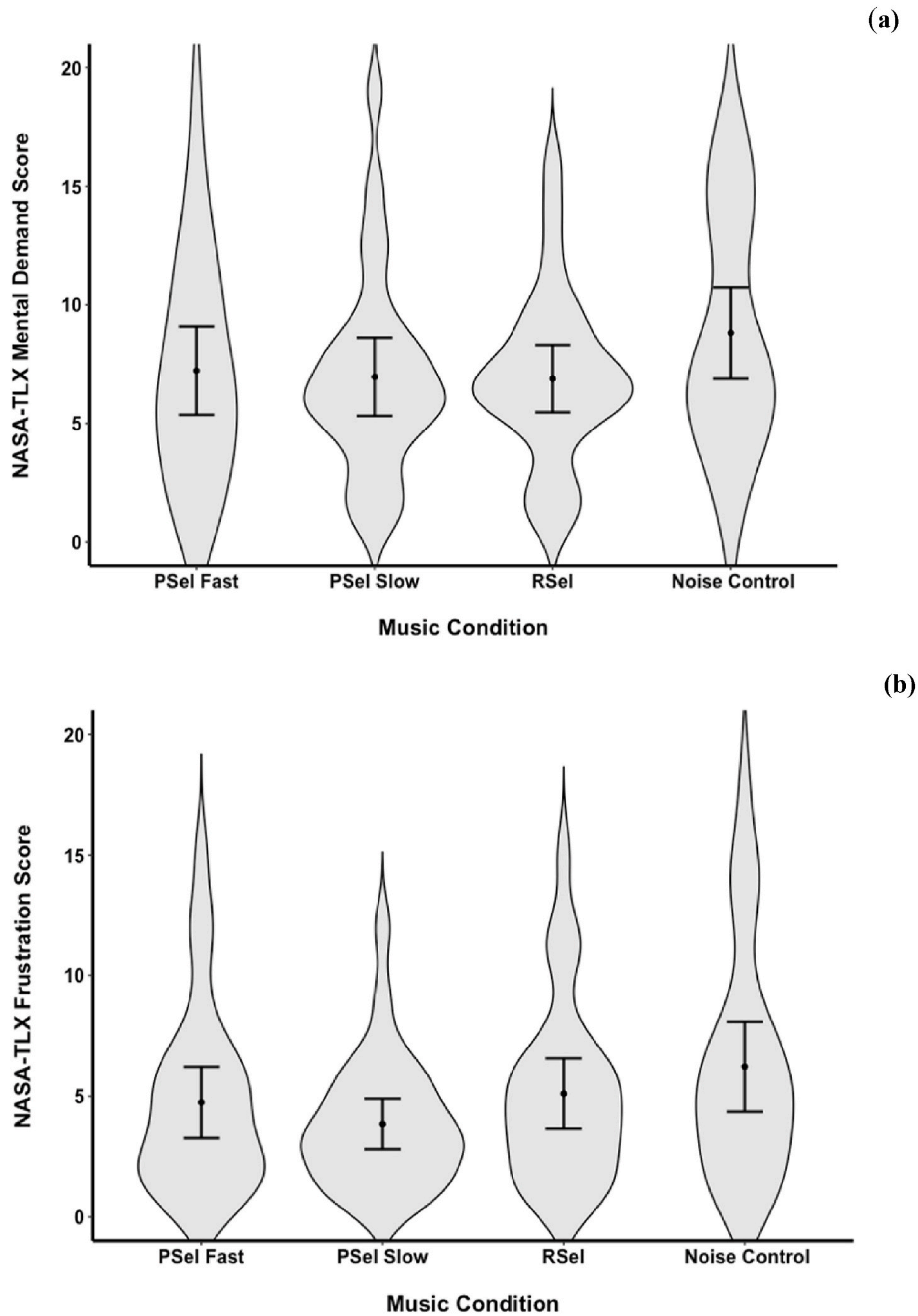

Fig. 4. The main effect of condition for (a) NASA-TLX mental demand (p = .036) and (b) NASA-TLX frustration (p = .007) scores. *Note.* Error bars represent 95% confidence intervals; NASA-TLX = NASA Task Load Index; PSel = participant selected; RSel = researcher selected.

extroverts recorded lower mean speed during the PSel fast-tempo music condition.

Pedal data were analysed using nonparametric ANOVAs, as the distributions were non-normal. A significant effect emerged only for the mean braking measure ($\eta_p^2 = .26$), associated with a large effect size. Participants made less use of the brake pedal in the PSel slow-tempo music condition, compared to PSel fast-tempo music, RSel music and the control condition. No significant effects of music condition emerged for any of the other variables (all $ps > .05$).

The ICCs for risk ratings across the three raters were relatively high: PSel fast tempo – 0.90; Psel slow tempo – 0.89; RSel Music – 0.93; and control – 0.88. Risk ratings did not meet the parametric assumptions and so nonparametric factorial rank-tests were used (Noguchi et al., 2012). The ANOVA-Type Statistic (ATS) is provided in the interests of concision; in no instance did differing results emerge in the less conservative Wald-Type Statistic (WTS). A Condition × Personality interaction emerged ($\eta_p^2 = .07$; see Table 2 and Fig. 5b), associated with a small-to-medium effect size. Examination of confidence intervals indicated that introverts attracted lower risk ratings in the PSel slow-tempo music and control condition when compared to extroverts. No significant main effects emerged (see Table 2).

4. Discussion

The main purpose of this study was to examine how four forms of auditory input influenced the core affect, cognitions, psychophysiology and driving behaviour of young males. In the formulation of hypotheses, the authors drew upon two relevant conceptual frameworks (Fuller,

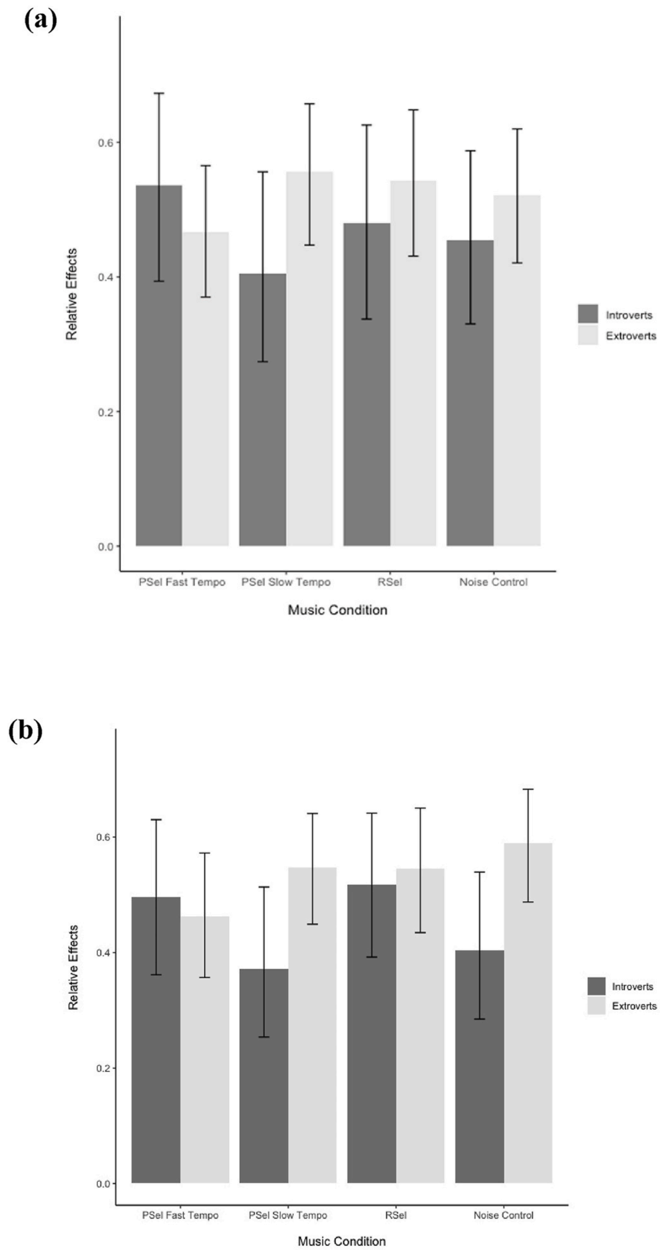

Fig. 5. The Condition × Personality interaction for (a) mean speed (p = .034) and (b) risk ratings (p = .043). *Note.* Error bars represent 95% confidence intervals; PSel = participant selected; RSel = researcher selected.

2011; Millet et al., 2019). The hypothesis that the PSel slow-tempo and RSel music conditions would engender the best affective state for simulated urban driving (H_1) was accepted (see Fig. 3). The hypothesis that PSel slow-tempo and RSel music conditions would lead to the lowest RSME and NASA-TLX scores (H_2) was not accepted. The hypothesis that PSel fast-tempo music would elicit higher blink frequency, subjective mental workload (i.e., measured using the NASA-TLX) and HR than the remaining conditions (H_3) was not accepted. The hypothesis that PSel slow-tempo music and RSel music would have a positive influence on driving behaviour (H_4) was not accepted. The null hypothesis (H_5) was accepted in relation to the series of exploratory analyses. It is notable, however, that personality had a moderating influence on driving behaviours: introverts recorded lower mean speed under PSel slow-tempo music and extroverts, similarly so, under the PSel fast-tempo music condition (see Fig. 5a). Moreover, the risk ratings attracted by introverts were lower in the PSel slow-tempo and control conditions (see Fig. 5b).

4.1. Core affect

There is a sizeable literature spanning many spheres of human endeavour that links music and the manipulation of its qualities (e.g., tempo and sound intensity) with core affect (e.g., Ainscough et al., 2019; Pottratz et al., 2021). Among all of the dependent measures included in the present study, it was affect that appeared to be most sensitive to the auditory manipulation and the results were in the expected direction (see Fig. 3). The aspect of this finding that is of the greatest import from a safety perspective concerns the relatively high affective arousal score elicited by the PSel fast-tempo condition. There is over a 2-point mean difference between the PSel slow and RSel conditions when compared with PSel fast-tempo music (see Table 1). The implications for safety-relevant driving behaviours of such high levels of arousal include speeding, risky manoeuvres and errors of under-inclusion (i.e., inattentiveness; Scott-Parker, 2017). These potential dangers are accentuated when the music is both fast and loud (Brodsky, 2002; Mizoguchi and Tsugawa, 2012; Ünal et al., 2012).

With reference to Millet et al.'s (2019) conceptual model, the PSel fast-tempo music has the potential to mediate a broad range of driving outcomes, as do gender, age and driving experience (see Fig. 1). We sampled young, male drivers in the present study – identified as one of the most at-risk groups on British roads – who have a tendency to self-select loud, fast-paced and aggressive music (Brodsky and Slor, 2013; Brodsky et al., 2018). Fuller's (2011) theoretical contribution details how drivers constantly adjust their behaviour in line with their perceived capability to match driving demands. Given that perceptual input can moderate these demands, a key implication of the present findings for core affect is that the promotion of happy–calming music in Circumplex Model terms, in the slow-to-moderate tempo band (i.e., 60–110 bpm), is likely to optimise the affective state of young men in the context of urban driving. Slower, more sedate music is likely to result in suboptimal levels of arousal, with attendant implications for attentional processing (Brodsky and Kizner, 2012). It might also lead to boredom and irritation (Brodsky et al., 2018).

4.2. Mental effort

The cognition-related findings from the RSME and NASA-TLX were not as compelling as those for core affect (see Table 2). The non-acceptance of H_2 was due to a lack of main effects of condition for the RSME and most NASA-TLX items but for the latter, a main effect with significant pairwise comparisons did emerge for frustration. Participants found the urban traffic-noise control to be more frustrating than PSel slow-tempo music (see Fig. 4b). Similarly, for mental demand, while no significant pairwise differences emerged across conditions, participants found the urban traffic control to be more mentally demanding than the music conditions (Fig. 4a). This hints at the propensity for calming–soothing music to serve as an antidote to frustration and reduce both mental demand and aggression in noisy urban settings (Brodsky and Kizner, 2012). Personality did not appear to moderate mental effort ratings and no significant Condition × Personality interactions emerged (see Table 2). It is notable that in terms of mental effort and driving-related cognitions, personality dimensions do not feature *prominently* in the two theoretical frameworks underlying the present investigation (Fuller, 2011; Millet et al., 2019).

4.3. Eye blinks

The data for mean eye blinks per min did not reveal any interaction or main effects. The Condition × Personality interaction was, however, associated with a medium effect size and suggested high blink rates for extroverts. This might be explained with reference to introverts' purported superior ability to narrow their attention, meaning that they had less need to blink (Blumenthal, 2001). Moreover, there is evidence that extroverts appear to have higher dopamine levels (Depue and Fu, 2013), and high blink rates are associated with increased presynaptic dopamine availability (Jonkees and Colzato, 2016).

4.4. Cardiac data

The experimental manipulations appeared to have no influence on the cardiac variables of HR and HRV (SDNN and RMSSD). This shows how the subjective differences that emerged in affective arousal were not mirrored in physiological processes. The driving task was relatively short and perhaps longer exposure to the music conditions (i.e., over a lengthy urban route) would have elicited differences, particularly in lower HR with PSel slow-tempo and RSel music when compared with PSel fast-tempo music (cf. Brodsky, 2002).

4.5. Driving behaviour

There were no main effects either of condition or personality on driving behaviour (see Table 2). The strong two-way Condition × Personality interaction that emerged pointed towards the benefits of PSel slow-tempo music for introverts and the benefits of PSel fast-tempo music for extroverts (see Fig. 5b). The lower mean speeds recorded can be interpreted with reference to differences in the response to the neurotransmitter dopamine between introverts and extroverts. Essentially, extroverts exhibit greater sensitivity in their dopamine reward network than introverts (Depue and Fu, 2013). When we consider this phenomenon in light of the findings for mean speed, we might speculate that extroverts' dopamine network was perhaps more sensitive to the PSel fast-tempo music, which led them to focus intently on the specifics of the task at hand (i.e., driving safely, observing the speed limit). Contrastingly, the comfort afforded by PSel slow-tempo music possibly led to optimal task focus in introverts. There is emerging evidence to suggest that introverts report a preference for slow-tempo music in a driving context (Niu et al., 2020).

The main effect of condition for braking data shows how participants made less use of the brake pedal in the PSel slow-tempo condition (see Tables 1 and 2). There are two plausible explanations for this finding. First that the introverts' tendency to drive slower in this condition led to less use of the brake pedal overall. Conceivably, the main effect was driven primarily by the behaviour of introverts, even though a significant Condition × Personality interaction did not emerge for this variable (see Table 2). Second, that the calming effects of this music condition led participants, regardless of their personality, to exercise superior anticipation, which, in turn, led them to make less use of the brake pedal. Given the lack of effect of the auditory conditions on behavioural variables, it is clear that a range of music conditions at 70 dBA did not have a deleterious effect.

The risk ratings indicate how introverts attracted lower scores in the PSel slow and control conditions (see Table 2). This is an intriguing finding but mirrors what was reported earlier in this subsection in relation to mean speed. The PSel slow music not only reduced the mean speed of introverts but also led to them attracting lower risk ratings. This illustrates the potential benefits of self-selected slow music for introverted drivers. Recent evidence has corroborated this finding, as it has been shown that introverts are more susceptible to the effects of music, while they also report a preference for slow-tempo music during driving (Niu et al., 2020). It seems plausible that, for introverts, self-selected slow music might elicit the optimal soundscape and mental state for urban driving.

The present findings support those from a clutch of past studies showing that, while music can have measurable psychological effects, there are no negative consequences in terms of safety-relevant behaviours (e.g., smooth braking, eyes directed on the road, lateral control), even in high-load conditions such as dense urban driving (Navarro et al., 2018; Ünal et al., 2013; van der Zwaag, 2012). In terms of Fuller's (2011) model, it could be that task demands were not sufficiently high for PSel fast-tempo music condition to compromise participants' capability to deal with additional demands. Apropos Fuller's notion of *risk allostasis* – that drivers seek to maintain risk homeostasis through adaptive change to meet perceived and anticipated demands – it might be argued that greater "adaptation" should have been prompted by the demands posed within the simulation. The implication is that future studies should have a more overt focus on risk taking and illegal manoeuvring.

4.6. Strengths and limitations

The present study included three experimental conditions and an ecologically valid control that facilitated an analysis of how agency in music selection and tempo influenced a range of psychological, psychophysiological and behavioural variables. Unlike many studies in this literature (e.g., FakhrHosseini and Jeon, 2019; Ünal et al., 2012), extensive efforts were made to standardise the psycho-acoustic properties of each of the playlists used ($k = 3$). The introversion–extroversion dimension of personality was explored, as this has been identified as an important moderator in music aesthetics (North and Hargreaves, 2008). The design was robust and the analyses powered with reference to related work (Brodsky and Kizner, 2012). A fulsome array of analyses was computed (parametric and nonparametric), prefaced by a thorough data diagnostics process (Tabachnick and Fidell, 2019).

A potential limitation is that task demands may not have been sufficiently challenging for the present music conditions to disrupt driving performance (cf. Fuller, 2011). Although a logistical challenge due to the high number of experimental conditions required, future studies might seek to cross different music programmes with varying levels of task difficulty (cf. Ünal et al., 2012). A limitation pertaining to music delivery is that different levels of sound intensity were not investigated (i.e., high vs. low). There is scope for sound intensity to bear influence on mental demand, given that high intensities can interfere with information processing (Mizoguchi and Tsugawa, 2012; Ünal et al., 2012). In view of the fact that participants knew they were being observed, there is a possibility they drove more cautiously, and so simulator-based performance may not fully represent their real-world driving behaviour (Zöller et al., 2019).

Although we found that the PSel slow-tempo and RSel conditions elicited the lowest affective arousal scores (see Table 1), we did not pre-establish each participant's optimal level of affective arousal for an urban driving task. We deemed that moderate scores for arousal would be optimal based on the verbal anchors that are attached to the Affect Grid (Russell et al., 1989). It is probable that some people can drive safely in an urban environment in a state of moderate-to-high arousal. There is a need for future research to examine such individual differences in terms of optimal arousal in the context of urban driving. Nonetheless, given the attentional demands of a dense urban setting, a high-arousal state is likely to be undesirable for the majority of drivers (Wen et al., 2019), and for introverts in particular (Niu et al., 2020). An additional limitation could be that participants were not tested at the same time of day, meaning that diurnal variations in arousal are a possible source of error (Lenné et al., 1997). We used randomly-presented triggers (events) in the simulation to maintain ecological validity. Such an approach does not facilitate a standardised (across participants) assessment of risk-related behaviours and vehicular control in relation to each trigger.

5. Conclusions and recommendations

The present findings add weight to the claims of previous studies in the applied ergonomics literature regarding the propensity of music to regulate drivers' affective state (Brodsky and Slor, 2013; van der Zwaag et al., 2012). A clear finding to emerge is that, regardless of the type of auditory manipulation, music conditions administered at 70 dBA had little bearing on the safety-relevant driving behaviour of young males (see Table 2). An exception concerns the two-way interaction of Condition × Personality, wherein it emerged that introverts drove slower under the PSel slow-tempo music, while extroverts did likewise under the PSel fast-tempo music. Another interesting finding was that participants used the brake pedal less in the PSel slow-tempo condition, possibly due to better anticipation.

No significant findings emerged for psychophysiological measures (i.e., eye-blink rate, HR and HRV), which might be due to the relatively short task duration of the simulated driving task. Notably, a significant Condition × Personality interaction did emerge for risk ratings, with introverts exhibiting safer driving behaviour under the PSel slow-music tempo condition. This finding hints at how slow-tempo music might be beneficial to the performance and safety of drivers with an introverted personality. The converse did not apply, in terms of extroverts' risk ratings being positively influenced by PSel fast-tempo music (see Fig. 5b). For this group, while PSel fast-tempo music appeared to work best in terms of regulating their driving speed, examination of 95% CIs did not show a corresponding effect in terms of safer driving behaviour (i.e., lower risk ratings).

There are theoretical, methodological and practical implications that emanate from the present study, which will drive future exploration in this area. From a theoretical perspective, the provision of a range of task-difficulty conditions or standardised triggers within conditions will provide scope to test the predictions pertaining to the notion of risk allostasis in Fuller's (2011) driver control theory (i.e., by providing simulations with instances of greater perceived risk). Similarly, this approach would enable researchers to test the moderating influence of contextual/environmental factors vis-à-vis Millet et al.'s (2019) conceptual framework (see Fig. 1).

From a methodological standpoint, the use of the same music conditions delivered at different levels of sound intensity (e.g., 70 and 80 dBA) would further understanding of the tempo by intensity interaction. Given the present focus on young men, it would be a worthwhile endeavour to examine whether young women are better able to parallel process (i.e., with music as a secondary task during driving; see Cotten et al., 2014). The main practical implication is that at 70 dBA, music applied in a simulated urban setting does not appear to predispose drivers to greater risk regardless of its tempo or who selects it (i.e., participant vs. researcher). It should be noted, however, that young, male drivers often play music at *much* higher sound intensities – for which it is difficult to obtain ethical clearance for test purposes – and that reckless drivers might not readily volunteer to be examined in the context of a scientific study.

A further practical implication pertains to the training required by neophyte drivers to obtain their full licence. In order to mitigate the potentially deleterious effects of music on driving behaviour, trainees should be tutored in how in-vehicle music listening can affect driving performance. Similarly, accident prevention campaigns might aim to raise drivers' awareness about the effect of music on driving performance. With respect to in-vehicle infotainment system design, it would be useful for a visual warning to appear in the case of fast and excessively loud music, to highlight how it might impair driving performance. Such messages could be tailored to the driver's demographic profile (e.g., age and personality) and supported by mobile phones and in-vehicle technologies that function as driving assistants.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary materials relating to this article can be found online at https://doi.org/10.1016/j.apergo.2021.103436. The datafile associated with this study can be accessed at https://figshare.com/s/1f61eeaafce4ffbfb2a1.

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