The influence of auditory feedback on speed choice,

violations and comfort in a driving simulation game

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Two experiments are reported which explore the relationships between auditory feedback (engine noise), speed choice, driving violations and driver comfort. Participants played a driving simulation game with different levels of auditory feedback in the form of engine noise. In Experiment 1, a between-subjects design revealed that no noise and low levels of engine noise (65dBA) resulted in participants driving at faster speeds than in the medium (75dBA) and high (85dBA) levels of engine noise conditions. The low noise feedback conditions were also associated with decreases in driver comfort. Experiment 2 also demonstrated that low levels of engine noise feedback (no feedback and 70dBA) were associated with increases in driving speed, and driving violations relative to higher levels of feedback (75dBA and 80dBA). Implications exist for current car manufacturing trends which emphasise a growing increase in noise insulation for the driver.

1. Introduction

The government was targeted with reducing the number of road deaths and serious injuries 40% by 2010 (when compared to average figures between 1994-1998). Although the number of deaths on British roads initially remained relatively stable, with fatal road casualty rates reported at 3431 in 2002; 3508 in 2003, 3221 in 2005 and 3201 in 2005, they have recently begun to fall. The number of people killed in road collisions reported to the police fell by 12% from 2,538 in 2008 to 2,222 in 2009, and the number of road casualties in 2009, at 222,100, represents a 31% reduction when compared to the 1994-98 mean. Nevertheless, as of 2009, there remain 26,906 people killed or seriously injured in 2009, 6% and 163,554 reported road collisions involving personal injury. Consequently, this is an area of great concern with strategies for addressing road safety becoming a hotly contentious topic of research.

There is evidence to suggest that drivers' speed choice is an important predictor of accident involvement (e.g. Wasielewski, 1984; West, French, Kemp & Elander, 1993; Horswill & McKenna, 1999), and that manipulating speed limits has a significant impact on accident involvement (e.g. Baum, Lund & Wells, 1989; Evans 2004). However, it has also been shown that in general drivers are poor at estimating and controlling their speed. For example, Denton (1966, 1976) showed that drivers' estimation of speed was effected by the "speed adaptation effect." This occurs when drivers slow down after a long period at high speed. Their subsequent estimations of speed are distorted, resulting in underestimations of speed of

travel. Briziarelli and Allan (1989) found that the presence of a head-up display speedometer did not have a significant impact on alleviating the speed adaptation effect. This may be because drivers' do not use speedometer readings, choosing instead to gauge their speed through cues from the car and external environment.

One cue that drivers may use to gauge their speed is auditory information. There is a growing body of research which suggests that auditory feedback plays a major part in the ability of a driver to make judgements about speed and speed choices. Beers and Hubert (1972) requested participants to accelerate (their own cars on a rural highway) to specific velocities using only sound as a cue. There was a marked tendency to under produce the requested speed in all cases, with the magnitude of the error increasing with increasing speed. This suggests that auditory feedback from the engine and plays a part in reducing speed through some perceptual mechanism. McClane and Wierwille (1975) found that the removal of auditory feedback of simulated engine noise resulted in approximately 3.2 km/h overproduction of speed, although it had no effect on the ability to maintain direction and position of the vehicle. Many authors are reporting that drivers who receive lower levels of auditory feedback in driving simulation tasks select faster driving speeds. For example, Horswill and McKenna (1999) used a fixed-base video driving simulator to test whether drivers' speed choice could be manipulated through auditory feedback. They found that drivers receiving lower levels of auditory feedback chose faster driving speeds and were poorer at speed estimation. Similarly, Matthews and Cousins (1980) found that the drivers of

small cars were able to estimate their speed more accurately than the drivers of large cars, and attributed this to the poorer sound insulation in the smaller cars. Walker, Stanton and Young (2006) also found auditory feedback to be particularly important in establishing a driver's situational awareness. If lack of auditory feedback is associated with poorer speed control and an increase in speed choice, then engine noise feedback is an important source of information for the driver.

Given the importance of auditory feedback in speed control and therefore in accident reduction, we might expect car interiors to employ sophisticated auditory feedback to assist the driver in making speed choices. However in fact, the opposite is true, with current car manufacturing trends emphasising noise insulation for the driver (Van de Ponseele & Kirtley, 2000; Trainham, 2005; Walker, Stanton & Young, 2006). Seemingly with every new model introduced, more steps are taken to reduce the level of noise experienced by the driver. The main reason why car manufacturers have sought to insulate the driver from engine noise, the association that has been revealed, or assumed to exist, between decreases in noise and higher subjective ratings of driver comfort (e.g. Namba, Kuwano, Kinoshita & Hayakawa, 1997; Parizet, Hamzaoui, Ségaud & Koch, 2003).

The relationship between increased noise levels and decreased driver comfort is not however as straightforward as it might appear. Firstly, the measure of 'comfort' to describe responses to sounds may be unreliable. Namba et al. (1997) noted that the relationship between noise and comfort in driving was bi-directional. They suggested that 'comfortable' driving softens the appraisal of sounds, while 'uncomfortable' driving makes the

6

impression of sounds more negative. Rather than 'comfort' and 'discomfort' the most frequently reported subjective response to noise is in fact 'annoyance', which is an abstract state resulting from the noise itself, or from its symptomatic or behavioural consequences (Selye, 1956). In addition, we know that the appraisal of noise comfort and loudness depends in part of the affective response to the particular sound, and its subjective meaning. For example, Kuwano, Namba and Fastl (1988) conducted a study where 'loudness', 'noisiness' and 'annoyance' were judged. Using exposure to both actual and artificial noises they found that differences in the subjective meaning of sounds had an important effect on judgements, with subjective meaning playing a greater role on judgements of 'noisiness' and 'annoyance' than on 'loudness'. This suggests that measures such as 'annoyance' and 'noisiness', (and we might also assume, 'comfort') are in part affective evaluations. Similarly, Namba, Kuwano, Açlar, Florentine & Da Rui (1991) orchestrated a cross-cultural study on noise problems incorporating data from Japan, Germany, the USA, China and Turkey. They found that respondents demonstrated a high degree of tolerance to the use of public loudspeakers in a residential environment if they were used for conveying necessary information. Fukuhara, Takanobu and Takamasa (2002) conducted experiments in vehicle acceleration performance and found the acceleration and accelerator pedal characteristic greatly influenced the evaluation of engine noise, across the two axis of 'quiet feeling' and 'sporty feeling.' While these studies assert driving performance variables due in part to vehicle differences, they also highlight the affective responses to different environmental cues.

The affect laden reaction to various sounds e.g. the subjectively pleasurable roar of a motorcycle, raises the issue that individuals react emotionally to sounds with the added assumption that certain affective states are preferred e.g. elation, pleasure or comfort, and others e.g. annoyance, tiredness or discomfort are disliked. This can be couched in terms of the pleasure-arousal hypothesis (e.g. Meharabian, 1977). In short, for unpleasant states, people prefer to feel bored (low activation state) over distressed (high activation state). For pleasant states, people prefer to feel elated (high activation state) over calm (low activation state). Västfjäll et al. (2002) conducted an experiment to look at the affective evaluations and reactions of participants to interior and exterior binaurally recorded sounds. The research addressed the questions 1) how individuals react to, and effectively evaluate sound and 2) how preference is related to affective reactions induced by the sounds. The authors found some support, using exterior car sounds, for the fact that preference for affective reactions to auditory stimuli was related to valence and activation. Bisping (1997) also proposed that affective evaluations are fundamental to evaluations of Car Interior Sound Quality (CISQ). They revealed that two major perceptual factors: pleasantness and powerfulness account for a massive 60-70% of the total variance in standard driving situations. CISQ can be described via these two perceptual factors forming a four quadrant scheme of sound quality with one axis defined by 'pleasant-unpleasant' and the other axis defined by 'powerful-weak'. These dimensions encompassed the role of affect in attitude to engine noise.

These studies imply that affective reactions guide performance whilst driving and determine responses to in-vehicle noise. This suggests that that relationship between engine noise and subjective comfort will not be a simple one but will be mediated by evaluations of the function of the noise itself. By focussing on noise reduction as a means of improving subjective comfort, car manufacturers may be failing to consider the important function of auditory feedback for the driver and the performance consequences of removing that feedback. Horswill and Plooy (2008) have already demonstrated that attenuating noise in a driving simulation by as little as 5dBA results in lower estimates of perceived speed. In the studies presented here we explore these issues by considering the relationship between various specific levels of auditory feedback, comfort, driving speed and violations, in a driving simulation game in which participants have to control the speed of the simulated vehicle. In particular, we are interested in considering whether there are specific levels at which auditory feedback can be provided that assist the driver in controlling their speed, without detrimentally effecting subjective evaluations of comfort.

1.1 Driving simulators as a research tool

Driving research usually relies on some form of driving simulator and one of the secondary aims of the current research was to investigate the adequacy of gaming software as an economic alternative to full scale high fidelity simulations. Frequently, research into driving behaviour has employed video based but non-interactive simulations. For example, Horswill and McKenna (1999) played video footage shot from a moving car to

participants on a normal VCR and television system. There was no attempt to simulate the drivers' experience. Similarly, Kim and Bishu (2004) used a video consisting of 40 scenes which would end at a point were the participant would have to make a decision about the appropriate course of action. These simulations do not offer any opportunity for participants to see the consequences of their chosen actions, nor do they replicate the normal driving experience. This lack of repercussions is a common feature of video-based simulators and here it was deemed necessary to try to create a more interactive environment that simulates the driving experience and allows participants to experience the outcomes of their driving choices.

Early attempts at interactive driving simulators were low fidelity and suffered more greatly than video based simulators from technical limitations. For example, Matthews and Desmond (2002) used the Aston Driving Simulator. This could only offer a limited display of the visual environment, and the situations that could be represented were restricted in complexity. Similar problems were experienced by Rogé (1996), and by Lenné, Triggs and Redman (1997), technical limitations meant that all the road straights were totally straight and flat and all the bends were uniform in curvature. The resulting course was more like a test track than a public road.

Despite the arguably low realism offered by the early simulators many studies were able to demonstrate experimental effects and there have been successful attempts to validate driving simulators as a research tool. Reed and Green (1999) compared the results obtained on both a high

fidelity and low fidelity driving simulator with those obtained in a real vehicle. The results obtained on the low fidelity simulator did not differ from those obtained on the high fidelity simulator and both sets of data corresponded well with those obtained in the real driving task. However, the simulator was shown to exaggerate imprecision within driving. Lee (2002) also investigated the validity of a fixed-base high fidelity interactive driving simulator by observing the driving performance of participants as they negotiated a set course of open roads and a simulator package. The driving performances of the participants were found to significantly correlate across the two methods of observation (R^2 = 0.66). Studies such as this suggest that findings obtained using fixed-base interactive simulators can be a valid representation of the real driving experience.

The current research used a p-c (experiment 1) or a games console (experiment 2) with a driving game to create an interactive fixed based driving simulator with a realistic projected drivers view and pedal and wheel controls. This set up favoured the need for experimental control, necessary to adequately control auditory feedback, over ecological validity, and is similar to, or improves upon, set ups used successfully in previous research. The use of gaming hardware and software provided a high fidelity interactive simulation. The reality of the simulation was supplemented by the use of wheel and pedal controls and by the projection of an enlarged drivers-eye image onto a wall in front of the participant. Of further benefit was the gaming facility to record and playback the experimental trials so that driving violations could be coded.

2. Experiment 1: The effect of auditory feedback on speed choice and perceived comfort

2.1. Method

2.1.1. Design. The effect of four different levels of engine noise feedback (no engine noise, 65dB(A), 75dB(A) and 85dB(A)) on driving performance and subjective measures of comfort and loudness were measured in a between subjects design. These levels of feedback were selected as ranging around the 60-80dB(A) noise levels that have been measured in a range of passenger cars (Kumar & Jain, 1994). Driving performance was measured by recording the top speed, average speed and total time (including five separate time splits) for each experimental trial. These measures were recorded by the simulation software. A short questionnaire measured subjective evaluations of engine noise comfort, loudness and simulator realism on 7 point Likert-type scales.

2.1.2. Stimuli and Materials. The simulation software (Test Drive 5 2000, © Infogames Entertainment) was installed and run on a RM Accelerator Personal Computer with a 1.8Ghz Pentium 4 processor in a 3x2 meter sound attenuated laboratory. The driving simulator was an off-the-shelf piece of proprietary software that satisfied the criteria for a good driving simulator including database creation, terrain modelling, vehicle dynamics, driver feedback and scenario control. The simulator displayed high resolution

tracks that incorporated multi-dynamic environment mapping and resulted in photo-realistic environments (Figure 1).

INSERT FIGURE 1 ABOUT HERE

For the experimental trials, the simulator displayed a first person perspective affording the participant a full screen view of the approaching environment. This was projected as a 120 x170cm image onto a white wall. This was an attempt to create a realistic driver-to-simulation scale. Analogue and digital speedometer, rev counter and gear indicator readings were also part of the head-up display available to participants. The visual display showed the rear view on a simulated rear view mirror. Logitech Wingman Formula Force USB steering wheel and pedals were used to control the simulation.

Engine noise feedback was played through wall-mounted Altec Lansing Speakers (model 221) positioned around the room. An Amplaid sound level meter was used to measure and define the speaker output required to produce the three levels of noise (65dB(A), 75dB(A) and 85dB(A))at the drivers' ear position. The noise levels represented the maximum noise output from the simulator at 40 mph. In the no feedback condition there was only ambient noise.

2.1.3. Participants. 48 participants volunteered to participate in exchange for course credit. There were 27 males aged 18-27 years (M= 23.5 years) and 21 females aged 18-35 years (M = 25.1 years). All reported normal or

corrected to normal vision and hearing, and all had a full driving licence. Participants in each experimental condition were matched for age and gender as far as possible. The average driving experience was 5.25 years

2.1.4. Procedure. Participants were run one at a time. They were given standardised instructions on the operation of the controls (steering wheel, brake and accelerator pedals) and a 5 minute practice run to familiarise them with the controls and driving environment. They were instructed to "Drive as you would in reality, observing normal traffic laws in this country." During the experimental trials, all the participants drove the same pre-set course. A questionnaire administered following the experimental trials assessed subjective evaluations of engine noise comfort, loudness and simulator realism on a 7 point Likert-type scale. Each session lasted approximately 20 minutes.

2.2. Results and Discussion

2.2.1 Average driving speed. The measures of top speed, average speed and total time taken were all perfectly correlated, average speed was used in analysis as the measure of driving performance.

Analysis of variance revealed a significant effect of noise level on average speed ($F_{(3,44)} = 9.02$, $p < .01$). Sidak pair-wise comparisons revealed significant differences ($p < .01$) between no engine noise ($M = 68.5$ mph.) and 75dB(A), ($M = 41.5$ mph.) and between no engine noise ($M = 68.5$ mph.) and 85dB(A), ($M = 41.08$ mph.). There were also significant differences ($p > .05$) between 65dB(A), ($M = 59.83$ mph.) and 75 dB(A), ($M =$

41.5 mph.) and between 65dB(A), (M = 59.83 mph.) and 85dB(A), (M = 41.08 mph.). Conditions of no engine noise feedback and quiet feedback resulted in faster average driving speeds than engine noise feedback in excess of 75dB(A).

2.2.2. Age and gender as covariates. Age and gender are often cited in the literature as determinants of speed choice and driving errors or violations (e.g. Blockey & Hartley, 1995; Schiff & Oldak, 1990). Although age and gender were not the primary interest of this investigation, and were not distributed equally across experimental conditions, they were investigated as possible covariates. ANCOVA revealed a significant main effect of age on average speed ($F (1,43) = 7.09$, p< .05), and the significant effect of engine feedback level remained present ($F (3, 43) = 9.62$, p<.01). A significant negative correlation between age and average speed across all noise conditions ($r (49) = -.334$, p< .05) revealed that older participants drove more slowly. There was also a significant main effect of sex on average speed ($F (1,39) = 5.67$, p<.05), with male participants (M = 57.76 mph.) driving faster across all conditions than female participants (M = 46.68 mph.). Again, the significant effect of engine feedback level remained present ($F (3, 43) = 7.64$, p<.01).

2.2.3. Subjective measures. Subjective judgements of comfort, loudness and realism were all measured on 7 point scales. In terms of interrelations among these measures, Pearson correlations revealed a significant positive correlation between comfort and subjective loudness ($r (48) = .49$, p <.01),

so that as subjective loudness increased, comfort increased. Realism ratings showed no relationships with any subjective or objective measures (M = 3.2, 'somewhat realistic').

There was a significant effect of engine feedback level on subjective comfort ratings ($F(3,44) = 10.71$, $p<.01$). Sidak post-hoc tests revealed significant differences between the no feedback condition and 65dB(A) ($p<.01$), 75dB(A) ($p<.01$), and 85dB(A) ($p<.05$). Participants in the no noise condition were significantly more uncomfortable than those with feedback noise.

Similarly there was a significant effect of engine feedback noise level on perceived loudness ($F(3,44) = 64.35$, $p<.01$). Sidak post-hoc analysis revealed significant differences between the no feedback condition and 65dB(A) ($p<.01$), 75dB(A) ($p<.01$), and 85dB(A) ($p<.05$). Participants in the no noise condition perceived significantly lower levels of loudness than those in any of the auditory feedback conditions.

INSERT FIGURE 2 ABOUT HERE

Figure 2 summarises the relationship between engine noise feedback, speed choice, perceived comfort and perceived loudness. A gradual increase in engine noise feedback results in a decrease in average speed. This effect is most pronounced between the 65 and 75 dB(A) conditions. In addition, as engine noise feedback increases over 65dB(A), perceived loudness and subjective comfort both increase. These data suggest that within the 65-85 dB(A) range, engine noise feedback helps to lower speed choice and

increases perceptions of comfort. Removing engine noise feedback increases driving speeds and adversely affects ratings of perceived comfort.

3. Experiment 2: Effects of engine noise feedback on driving speed and violations

In the study described above, three 10 dB increments in engine noise level (65, 75 & 85 dB) were used to show that as engine noise feedback increased from 65-85 dB, so speed choice was reduced and subjective comfort increased. In the study reported below, three 5 dB increments in engine noise feedback level (70, 75 and 80) were used to explore in more detail the effects of engine noise feedback in the 70-80 dB range. In addition, the effect of engine noise feedback on driving violations was recorded.

3.1. Method

Aspects of the methodology were as described in Experiment 1, unless otherwise stated.

3.1.1. Design. The effect of four different levels of engine noise feedback (no engine noise, 70dB(A), 75dB(A) and 80dB(A)) on average driving speed, driving violations and subjective measures of realism were measured in a within subjects design. The order in which participants completed the experimental conditions was counterbalanced.

Average driving speed was calculated by dividing course completion time, by course distance (both measures were recorded by the software).

Driving violations were recorded and classified according to severity. The classification system was based on that of Åberg and Rimmö (1998). Minor deviations, when more than one wheel left the normal road area, were classified as 'excursions', and more severe deviations that resulted in an impact with another object were recorded as 'collisions'. If a collision occurred then it negated the excursion that must also have occurred. These two classes of violation were combined to create an overall violation score which reflected the magnitude of the driving violations (with higher scores indicating less safe completion of the course).

A short questionnaire was used in pilot work to assess the realism of the simulation and the level of disturbance experienced.

3.1.2. Stimuli and Materials. A Sony Playstation2 games console playing the driving game Gran Turismo 4 by Polyphony Digital was used to provide the driving simulation. The course used was Circuit de Sarthe II, a digitised representation of the circuit used in the Le Mans 24 hour endurance race up until 1990, it was chosen because it is comprised of roads that are open to the public for the majority of the year.

3.1.3. Participants. 24 participants volunteered to participate in exchange for a course credit. There were 12 males aged 29-42 years (M = 29.5 years) and 12 females aged 19-31 years (M = 26.1 years). All reported normal or corrected to normal vision and hearing, and all had a full driving licence. The average driving experience was 9.88 years.

3.1.4. Procedure. The realism of the simulation was assessed in pilot work. Seven participants (mean age = 29 years) drove the course and were stopped at 5 points and asked to estimate the speed limit and rate the realism and the level of external disturbance on a 10-point scale.

In the main experiment, the order in which trials were presented to participants was counterbalanced, and there was a 5 minute break between successive trials. In addition to the performance measures recorded by the simulator, driver violations were recorded and coded by the experimenter. No post experimental questionnaire was administered.

3.2. Results and Discussion

3.2.1. Realism of the Simulation. The mean realism score was 7 (st.dev. = 1.71) indicating that the simulation offered a high degree of realism. The mean score for disturbance was 4.94 (st.dev. = 1.82), indicating a medium level of disturbance and average estimated speed limit was 50 mph (st.dev. = 7.9), which was the actual speed limit of the road used for the trials.

3.2.2. Average driving speed. Average driving speeds are shown in Table 1 as a function of level of engine noise feedback. Analysis of variance revealed a significant effect of noise level on average speed ($F_{3,69} = 3.15$, MSe = 43.73, $p<0.05$). Sidak pair-wise comparisons revealed significant differences between no engine noise and 80dB(A) feedback conditions ($p<.05$). Conditions of no engine noise feedback resulted in faster average driving speeds (M = 70.88 mph.) than engine noise feedback of 80dB(A), (M =

65.23 mph.). Although no other conditions differed significantly from each other, the differences between the control condition and 75dB(A) and between 70dB(A) and 80dB(A) both approached significance (p= 0.09 and p=0.06 respectively).

INSERT TABLE 1 ABOUT HERE

3.2.3. The effect of age and gender on speed. In order to account for any possible effects of participant sex on average speed, the data were re-analysed with sex as a between subjects measure. Sex had a significant effect on average speed ($F_{1,22}$ = 856, MSe = 515.20, p<.01), with males driving on average 25mph faster than females across experimental conditions. The effect of noise level on average speed remained ($F_{3,66}$ = 3.01, MSe = 45.66, p<.05) and there was no interaction between participant sex and noise level ($F_{3,66}$ = .02, p>0.05).

Participant age and driving experience were highly correlated (r = 0.76, p<.01), consequently only age was used in further analysis. The possible effects of age on average speed were considered by re-analysing the data with age as a between subjects measure. The effects of engine noise feedback level on average speed remained significant ($F_{3,27}$ = 3.91, MSe = 37.27, p<0.05) but there was no significant effect of age and no significant interaction between age and feedback level.

3.2.4. Violations. Total numbers of violations are shown in Table 2 as a function of level of engine noise feedback.

INSERT TABLE 2 ABOUT HERE

Analysis of variance (with the Greenhouse-Geisser adjustment) revealed a significant effect of noise level on violations (F 1.5, 34.4 = 4.11, MSe = 158.5, p<0.05). Sidak pair wise comparisons revealed significant differences between no engine noise (n=18.55) and 80dB(A) feedback conditions (n=10.42), and between the 70dB(A) (n=13.92) and 80dB(A) (n= 10.42) conditions (p<.05). Differences between the no engine noise and 75dB(A) feedback conditions approached significance (p=0.053). Conditions of no engine noise feedback and low levels of feedback at 70 dB(A) resulted in more driving violations than engine noise feedback of 80dB(A).

3.2.5. The effect of age and gender on violations. In order to account for any possible effects of participant gender on violations, the data were re-analysed with sex as a between subjects measure. Sex did not have a significant effect on violation scores and there was no interaction between sex and feedback level. The effect of noise level on violations remained (F 1.49,32.86 = 4.26, MSe 152.62, p<.05).

The possible effects of participant age on violations were also considered. The data were re-analysed with age as a between subjects measure. The effects of engine noise feedback level on violations remained significant (F 3,27 = 17.63, MSe = 18.82, p<.01), and there was no significant effect of age on violations, nor an interaction between age and engine noise feedback level..

The results of the experimental task show that there is a clearly significant effect of the level of engine noise feedback on average driving speed and on the number of driving violations committed. Participants drove faster and committed more driving violations in the no engine noise feedback condition than in the 80dB(A) feedback condition.

4. General Discussion

The results of Experiment 1 indicate that driving in conditions of no engine noise feedback or low levels of feedback (0/65dBA) results in faster driving speeds than conditions of higher engine noise feedback (75/80dBA). While higher levels of engine noise feedback result in slower driving speeds, they do not increase levels of subjective discomfort. Indeed, the no noise condition is the most subjectively uncomfortable, and there is no increase in subjective discomfort with increasing levels of engine noise feedback. Experiment 2 supports these findings, again participants drove faster, and also committed more driving violations, in the no feedback noise condition when compared to the high feedback noise condition (80dBA).

Taken together these results suggest that engine noise feedback is one important cue for speed control in driving and that such feedback also reduces driving violations. As such, engine noise can be characterised as 'feedback' rather than 'noise', and we should expect to preserve this important source of information for the driver. Furthermore, auditory feedback presented at the levels used here is associated with increased,

rather than decreased, driver comfort. The positive correlation between loudness and comfort further implies that the engine noise is not unwanted. These findings obviously require additional exploration before they can be generalised from these tasks to the real driving environment. Auditory feedback is only one of many possible cues that drivers may use to gauge speed and the extent to which cues may vary in importance in different driving simulation environments compared to in the real world is not known. Similarly the effect of these levels of auditory feedback on secondary tasks such as phone use, or conversation, or over prolonged periods of time, are not known (the driving task used here involved no external distractions and was relatively short, about 20 mins.). Additionally, the positive correlation found between engine noise and comfort may be a more a function of the driving task used here rather than a feature of real-world driving, but nevertheless an environment of very low engine noise feedback is likely to be undesirable even in real world driving.

The fact that manipulating auditory feedback had a significant effect on speed of driving, despite the presence of a speedometer which indicated actual speed, is intriguing. This suggests that the effect of manipulating feedback levels is strong enough to overrule some of the information obtained visually. It would seem logical to assume that the presence of a speedometer would allow participants to judge their speed perfectly well. Briziarelli and Allen (1989) showed that the presence of a head-up display speedometer did not have an effect on the speed adaptation effect. The results here seem to suggest a similar finding. The findings seem to suggest that participants were aware of what speed they were travelling at,

however, the change in feedback levels meant that their perception of what speed was appropriate changed according to condition.

There are potential implications for current car design and also for the design of future vehicles such as electric cars. The data suggest that the current trend within car design, to reduce noise levels for the driver, should be pursued with some cautions. These experiments show that levels of engine noise feedback up to at least 80dB(A) can benefit the driving task without having a negative impact on subjective comfort, and it is likely that at least some level of engine noise provides desirable feedback in the real driving task. Of prime interest for further research is the issue of which component of the auditory feedback has the most effect? If we could isolate the performance-enhancing aspects of the auditory feedback then we could consider sonifying aspects of the cars' performance and so design artificial auditory feedback that maximises the benefits to performance and also to driver comfort. The way in which other sources of in-car auditory information interact with engine noise feedback also needs to be considered.

The current research also revealed negative correlations between age and gender and driving speed, so that older drivers drove slower, and female drivers drove slower. These findings are consistent with those in the literature and are not the primary interest of the current investigation. What is important about the age and gender effects is that they did not interact with engine noise level or comfort ratings, so that the effects of engine noise feedback on speed reduction and comfort are consistent across these other variables known to effect driving performance. Although male

participants drove faster than their female counterparts, they did not commit significantly more violations. This can be explained in terms of the nature of the simulator package. The simulation did not include any other vehicles and consequently, participants did not encounter any situation where they had to make judgements about how to interact with other vehicles. Statistical evidence suggests that male drivers tend to drive faster with less consideration for other motorists than women. Such a tendency was shown within these experiments by the significantly greater speeds driven by male participants. However, this lack of consideration for others can be dangerous during normal driving and can often result in accidents, however, these types of accidents could not occur in this experiment. Instead the accidents that did occur were related to car control. The results of this experiment therefore seem to suggest that male participants commit fewer control related violations than women. An alternative explanation rests on experience with gaming software. Exposure to driving games was not measured here, however it is possible that higher levels of exposure to driving simulation games among the male participants may have reduced their violation scores relative to the females.

A secondary aim of the current experiments was to evaluate the use of gaming software as a tool for driving research. In experiment 1, the PC-based gaming software was evaluated on a 7-point scale and achieved a mean rating of 3.2, which corresponded to a judgement of 'somewhat realistic'. In experiment 2, the games console and software achieved a mean realism rating was 7/10, indicting that the simulation was considered realistic. The latter finding was further supported by a close correspondence

between the estimated speed limit for the course in experiment 2 (50mph) and the actual speed limit for the roads featured in the simulation (50 mph).

In acknowledgement of the fact that an evaluation of realism is probably a multi-dimensional construct including variables such as noise, car handling and environment, and is additionally complex because it requires evaluation against a known counterpart which is itself subject to many variables, we asked participants to justify their realism rating in an open ended answer. The aspects of the simulation that were most frequently cited as lowering realism were environmental aspects such as the lack of other vehicles, and pedestrians. Vehicle response was cited as a positive addition in terms of realism. While both simulations contained realistic terrain modelling to create a credible environment, they did not allow control or addition of other environmental variables e.g. road signs, speed limits etc., and participants reported using cues like building density to determine speed choices. Furthermore, the vehicles, whilst handling realistically did not respond to the environment in terms of damage. The findings of this study help illustrate the usefulness of low budget simulation with regards to research into driving.

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