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ISA Interface Study

by

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On behalf of

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Table of Contents

Executive Summary

This study examines various alternative designs for the Human Machine Interface (HMI) of Intelligent Speed Assistance (ISA). This driver assistant system is to be fitted to new vehicles sold across the EU, but the legislation does not specify a detailed specification for the driver interface. This work was designed to address that gap and make recommendations on interface design.

The work was carried out on a state-of-the-art driving simulator. Both objective (speed) data and subjective (questionnaire) data were collected. Five different HMIs were tested. Detailed descriptions of those HMIs can be found in section 2.3. The results identify Speed Control Alone, followed by the Haptic Pedal and Speed Control with Vibrating Pedal, as being acceptable HMIs. The findings further suggest that neither the Auditory Warning nor the Vibrating Pedal (without Speed Control) are good choices for ISA HMI.

1. Introduction

The 2019 revision of the EU General Safety Regulation and Pedestrian Safety Regulation (Regulation (EU) 2019/2144 of 27 November 2019) stipulates that Intelligent Speed Assistance is to be fitted to new motor vehicles sold across the EU. It also provides some details on what is meant by "Intelligent Speed Assistance". Article 3 states: 'intelligent speed assistance' means a system to aid the driver in maintaining the appropriate speed for the road environment by providing dedicated and appropriate feedback".

Article 6 provides more detail:

> "Intelligent speed assistance shall meet the following minimum requirements:
>
> (a) it shall be possible for the driver to be made aware through the accelerator control, or through dedicated, appropriate and effective feedback, that the applicable speed limit is exceeded;
>
> (b) it shall be possible to switch off the system; information about the speed limit may still be provided, and intelligent speed assistance shall be in normal operation mode upon each activation of the vehicle master control switch;
>
> (c) the dedicated and appropriate feedback shall be based on speed limit information obtained through the observation of road signs and signals, based on infrastructure signals or electronic map data, or both, made available in-vehicle;
>
> (d) it shall not affect the possibility, for the drivers, of exceeding the system's prompted vehicle speed;
>
> (e) its performance targets shall be set in order to avoid or minimise the error rate under real driving conditions."

In this text, clauses (a) and (c) provide some definition of the HMI for an ISA system. The crucial words are "*through the accelerator control, or through dedicated, appropriate and effective feedback*" and "*it shall not affect the possibility, for the drivers, of exceeding the system's prompted vehicle speed*." The second of these statements clearly stipulates that drivers must be able to override the ISA at will, while first indicates something about the quality of the HMI: "dedicated, appropriate and effective."

Nevertheless, the text of the regulation does not provide any specification of an HMI that meets the legislative requirements. This study aims to fill that gap, by evaluating a number of alternative HMI designs for ISA, looking both at their effectiveness in terms of promoting speed compliance and at their acceptability to drivers. All of the chosen HMIs allow drivers to override the feedback (i.e. to exceed the speed limit if they choose to do so, as required by legislation), but there are major differences in the feedback provided. In the experiment, the participants were not given the option to switch off the ISA feedback, since that would have effectively negated the purpose of the study. Acceptability to drivers is particularly important since it would be likely that drivers who felt annoyed by an ISA system would tend to switch it off, as allowed by clause (b) of the regulation, thus substantially reducing the safety benefit of ISA.

2. Methodology

2.1 Driving simulator

The experiment was conducted on the University of Leeds Driving Simulator. This simulator features a full-size car cabin enclosed within a spherical dome that is mounted on an eight-degrees of freedom motion base (hexapod connected to an X-Y table with 10 metre rails). This motion system provides realistic motion feel to the driver. The whole gantry (hexapod plus dome) can also slide longitudinally and laterally. Particularly relevant to this study, the longitudinal motion provides 5m of effective travel in each direction to mimic the vehicle's acceleration and braking.

The car is a Jaguar S-Type with all the controls operational. The 11-channel projection system provides a 300° field of view, with the side mirrors operating through LCD screens. There is tactile and haptic feedback through the pedals and the steering wheel to replicate forces experienced during driving. Additional haptic control of force or stiffness as well as controllable vibration can be added to the accelerator pedal feel. There is realistic and programmable sound to provide both the auditory sensation of driving as well as specific sounds and messages.

Figure 1: University of Leeds Driving Simulator: exterior and interior views

The simulator software collects data at 60Hz relating to driver behaviour (actions on the vehicle controls), the vehicle (position, speed, accelerations, etc.) and other autonomous entities in the scene (e.g. identity, position and speed). The software suite is built in-house and can be tailored to the requirements of each experiment.

2.2 Overall operation of ISA in the experiment

Speed limit compliance was assessed in terms of the posted speed limit. Initially, the vehicle was assumed to be compliant, i.e. below the speed limit. The vehicle was deemed to have become non-compliant and the HMI activated accordingly if the vehicle speed was greater than the posted speed limit for more than 1 second. If the vehicle was non-compliant, it was subsequently determined to be compliant if vehicle speed was below the posted speed limit for more than 1 second.

At each speed limit transition, the change to the speed limit was indicated externally with the relevant sign at the entrance to the new speed limit zone. The new posted speed limit became active when the sign was 5 metres ahead of the driver's position within the vehicle. Given the speed of the vehicle and the latency associated with the control system, this corresponded to the speed limit sign passing behind the nearside (left) A pillar. A visual indicator of the prevailing speed limit was presented on the dashboard in all conditions apart from the non-ISA baseline. In all the ISA conditions, an audible indicator confirmation of a change in speed limit was provided. This sound was a "bong", analogous to a cabin crew call bell on an aircraft. The posted speed limit (20, 30, 40, 50, 60, 70 mph) was shown on the dashboard in a standard speed roundel. If the vehicle speed was not compliant, then the speed roundel flashed at 1Hz, i.e. it was on for 0.5 seconds, then off for 0.5 seconds until speed was compliant once more.

2.3 ISA systems tested

All the versions of ISA featured the visual information and visual warning discussed in section 2.2. They also all featured the auditory bong at each change of speed limit. As mentioned earlier, the participants were not provide the option to switch off ISA support.

Five different versions of ISA were tested:

1. Auditory warning
2. Haptic (force feedback) pedal
3. Vibrating pedal
4. Speed control + vibrating pedal
5. Speed control

Condition 1: Auditory warning

When speed was non-compliant, bursts of a high pitch beep sound were played at intervals. In each burst there were three beeps played at 3.3Hz (0.75 seconds). Bursts of three beeps were initiated at 5-second intervals as long as the vehicle was non-compliant, meaning that there was 4.25 seconds of silence between each burst of three beeps.

Condition 2: Haptic pedal

The operation of the haptic pedal was based on the version that was found to be most effective in the simulator investigation carried out in the ecoDriver project (Hibberd et al., 2015). In that study, haptic force feedback (as opposed to stiffness feedback) was found to be the most effective in preventing over-acceleration, i.e. acceleration beyond a given point. Force feedback has the advantage of being able to indicate a specific point beyond which acceleration is discouraged.

In the ecoDriver chosen system, the extra force required to overcome the pedal resistance and depress the pedal beyond the inflection point was 40 N. For this experiment, it was necessary to have the inflection point fixed to the current speed limit. Thus the feedback force on the accelerator pedal was proportional to the vehicle speed relative to the posted speed, and the speed delta value was calculated as the delta percentage relative to the posted speed. The corresponding force was applied to the accelerator pedal feedback mechanism. The force feedback on the accelerator pedal for normal driving is around 20 N. As the delta percentage approached 0 (the vehicle speed reached the posted speed) the force on the pedal was increased slightly to warn the driver that he/she was near the speed limit. When the vehicle speed exceeded the posted speed, the force on the pedal increased rapidly, to resist the requested acceleration. However, the driver could push through the force feedback by continuing to press on the pedal. Once the vehicle speed was 6% higher than the posted speed, the force feedback on the pedal reduced quickly to a more normal value, at 30 N instead of 20 N).

When the vehicle entered a new speed limit zone with a lower limit, the pedal force was set to the high value (60N) for a maximum of either 5 seconds or until the speed excess fell to less than 5% above the new speed limit. This had the effect of warning the driver that he/she should now reduce speed. If the driver continued to maintain his/her current speed, the force again reduced to 1.5 times the standard force, i.e. to 30 N. The settings of the haptic pedal are shown in Figure 2. The Delta Value is: ((Vehicle Speed – Speed Limit) / Speed Limit)) x 100.

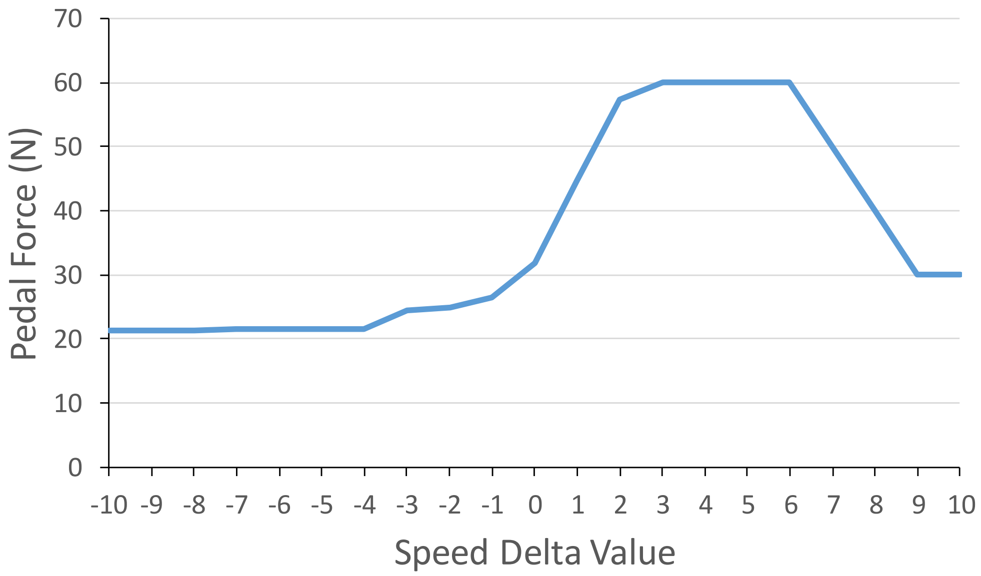

Figure 2: Configuration of haptic pedal

Condition 3: Vibrating pedal

As soon as vehicle speed became non-compliant, the accelerator pedal started to vibrate. Vibration continued until the vehicle speed was once again compliant. The vibration was analogous to the vibration signal on a mobile phone.

Condition 4: Speed control with kick-through and vibrating pedal

The speed control operated as a "dead throttle", which limited vehicle speed to the speed limit, unless the driver deliberately kicked through the limit. The speed of the vehicle was limited to 98% of the posted speed limit. The accelerator pedal functioned normally until the vehicle reached the posted speed limit; after this point, a further depression of the pedal would have no effect.

If the vehicle entered a new speed limit zone and the new speed limit was lower than the vehicle speed, then engine braking was used to decelerate the vehicle until its speed became compliant.

If the accelerator pedal was used to signal a kick-through (override of the limiter), then the speed limiter function was disabled, provided that a non-compliant speed was achieved within 3 seconds of the kick-through being signalled. If the non-compliant speed was not achieved within 3 seconds, then the kick-through request was aborted and the speed limiter reengaged.

Once the speed limiter had been overridden, it remained disabled until the vehicle speed once again became compliant. This occurred either by the driver reducing the vehicle speed to be lower than the limit, or by the vehicle entering a new speed limit zone in which the limit was higher than the current vehicle speed.

The kick-through operated as follows:

- A kick-through was signalled if:
    - The speed of the vehicle was above 15 mph (6.7 m/s, 24.1 km/h)
    - The accelerator pedal position increased by at least 30% of the full movement range within 0.25 seconds
- The kick-through signal was held on for 1 second before being reset
- When the kick-through function was activated, an indicator was shown on the dashboard for 1 second.

When vehicle speed was non-compliant, the accelerator pedal vibrated as in Condition 3.

Condition 5: Speed control with kick-through
This was identical to Condition 4, except that vibration feedback was not provided.

2.4 Experimental road

The experimental road was just over 14.3 km long and included every UK speed limit, as follows:

20 mph 503m
30 mph 3842m
40 mph 1672m
50 mph 755m
60 mph 5175m
70 mph 2389m

The same road was driven in all the experimental conditions. The drives began and ended on a rural single carriageway road with a 60 mph speed limit. In between were built-up areas with 30 mph and 40 mph limits as well as 20 mph zones. There was also a stretch of dual carriageway driving and of motorway driving.

Opposing traffic was present, but the vehicles in the direction of travel were always positioned so as to allow “free driving”, i.e. full control over speed choice. The driver was never required to slow down or stop to negotiate intersections and there were no red or amber traffic lights.

Auditory messages, in the form of telephone voice messages, were presented at intervals in order to encourage the feeling of being in a hurry. These varied between the drives, but essentially had the same content, e.g. a delivery driver reporting that he was getting close to the participant’s house and required a signature for a parcel.

2.5 Dependent variables

2.5.1 Speed compliance

Speed and other vehicle data was collected at 60 Hz. The main dependent variable was mean speed in a section which could then be compared to the speed limit.

2.5.2 Questionnaires

A series of questionnaire were administered after each drive to ascertain driver workload and acceptance of the ISA systems. The questionnaires used can be found in the Appendix. Following the initial baseline drive and each subsequent drive, the participants completed a NASA-TLX questionnaire (Hart and Staveland, 1988). No weighting procedure was used across the dimensions, so that the workload was assessed using the Raw Task Load Index (RTLX; Byers et al., 1989). The questionnaire probes into six dimensions of workload: mental demand; physical demand; time pressure; performance effort; and frustration level. The participants were provided with definitions of each. Scoring of each dimension is on a scale from 0 to 100.

The other questionnaires were only administered after each drive with a version of ISA. To probe acceptance of each system, the questionnaire of van der Laan et al. (1997) was used. This produces two scales each in a range from –2 to +2: *usefulness* (e.g. assisting) and s*atisfaction* (e.g. pleasantness).

The final questionnaire probed driver annoyance, which was considered particularly important since it would be likely that drivers who felt annoyed by an ISA system would tend to switch it off. The annoyance scale used was similar to that of Baldwin (2011), except that instead of using a 5-point Likert scale with 0 representing low annoyance, a continuous bipolar scale was used with the left side anchored at “Pleasant” and the right side anchored at “Annoying”. As for NASA-TLX, participants made a mark on a 10cm-long line which could then be translated into a score of 0–100. For analysis, 50 was subtracted from each score, creating a scale that ran from –50 (very pleasant) to +50 (very annoying) with zero as the neutral point.

Participants completed the annoyance questionnaire twice: once as though they were driving on their own and a second time as though they had a passenger in the front seat. It was hypothesised, that the participants might find a warning which could be detected by a passenger more annoying than a discrete one of which only the driver was aware.

2.6 Experimental design

The experimental design was within participant: each participant drove in each of the conditions. In order to eliminate any carry-over effects from driving with an ISA system, the first (baseline) drive was always without ISA support. The baseline drive was followed by driving with all five variants of ISA in counterbalanced order. The counterbalancing was implemented, so as to randomise the order of encountering the ISA variants and thus ensure that there were no systematic impacts from driving with one particular variant on behaviour with and acceptance of another.

The procedure for each participant was as follows:

1. Practice drive of around 15 minutes to provide familiarisation with the driving simulator
2. The baseline drive

3. The completion of the NASA TLX (workload) questionnaire for the baseline drive
4. The first drive with a variant of ISA
5. Completion of NASA-TLX questionnaire, Van der Laan questionnaire, annoyance questionnaire as if driving on own, and annoyance questionnaire as if driving with a front-seat passenger
6. Four more repeats of (4) and (5) for the further variants of ISA

The total elapsed time for each participant was approximately 2.5 hours.

Prior ethics approval for the study was obtained from the Business, Environment and Social Sciences joint Faculty Research Ethics Committee (AREA FREC) at the University of Leeds.

2.7 Participants

There were 30 participants in total, 15 male and 15 female. Mean age was 43.5 with a standard deviation of 14.5 years. Each held a full UK driving licence driving, and drove on at least three days per week or 50 miles per week. All completed informed consent forms.

3. Results

3.1 Speed compliance

Speed for each participant was recorded at 60Hz. In accordance with the recommendation of Lahrmann et al. (2012), the intervals for the speed measurements were converted from units of time to units of distance, e.g. speed every 10 metres as opposed to speed every second. However, this conversion probably makes little difference here, since all the driving was in free-flow conditions.

The chosen outcome measure was mean speed, i.e. a comparison of mean speed between the baseline drive and the drives with the different variants of ISA. The results are presented here separately for each speed limit and then for overall speed. It should be noted that the experiment was conducted with UK drivers, who generally tend to be compliant with speed limits.

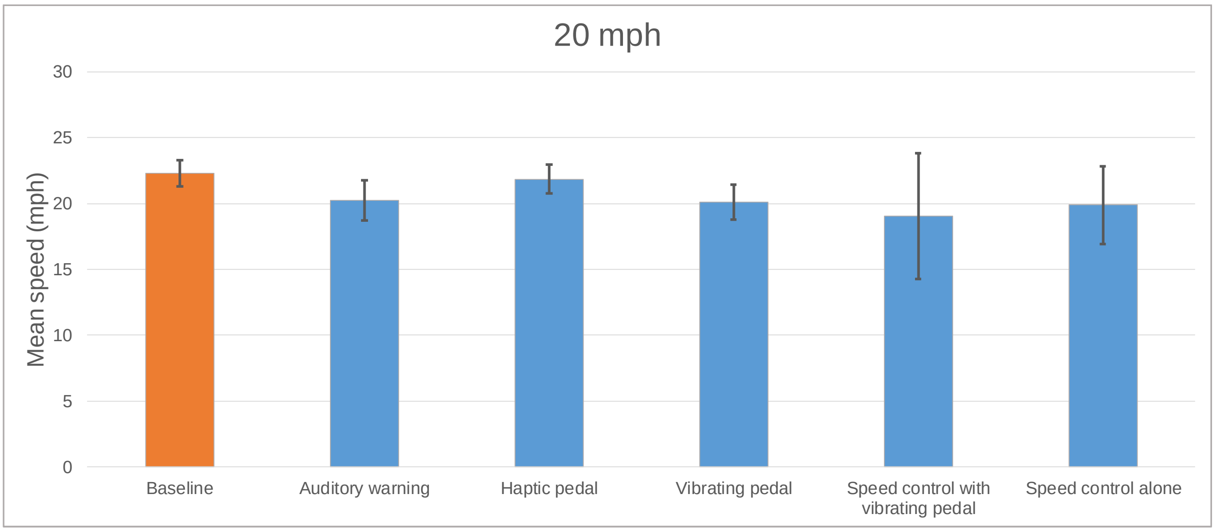

Figure 3: Mean speed by condition on 20 mph road sections

The mean speeds on road sections with a speed limit of 20 mph are shown in Figure 3. The "whiskers" in this graph and in the subsequent figures on speed show the standard errors. So here it can be observed that there is greater variability in speed when driving with the speed control and vibrating pedal system. Post hoc tests (Tukey's) indicated that only the Speed Control + Vibrating Pedal condition produced speeds that were significantly lower ($p \leq 0.05$) than the Baseline condition.

Figure 4 shows mean speed on the 30 mph road sections. Post hoc tests (Tukey's) indicated that there was a significant reduction in speed with ISA for three conditions: Auditory; Speed Control + Vibrating Pedal; and Vibrating Pedal. The Vibrating Pedal was the most effective of the ISA systems here.

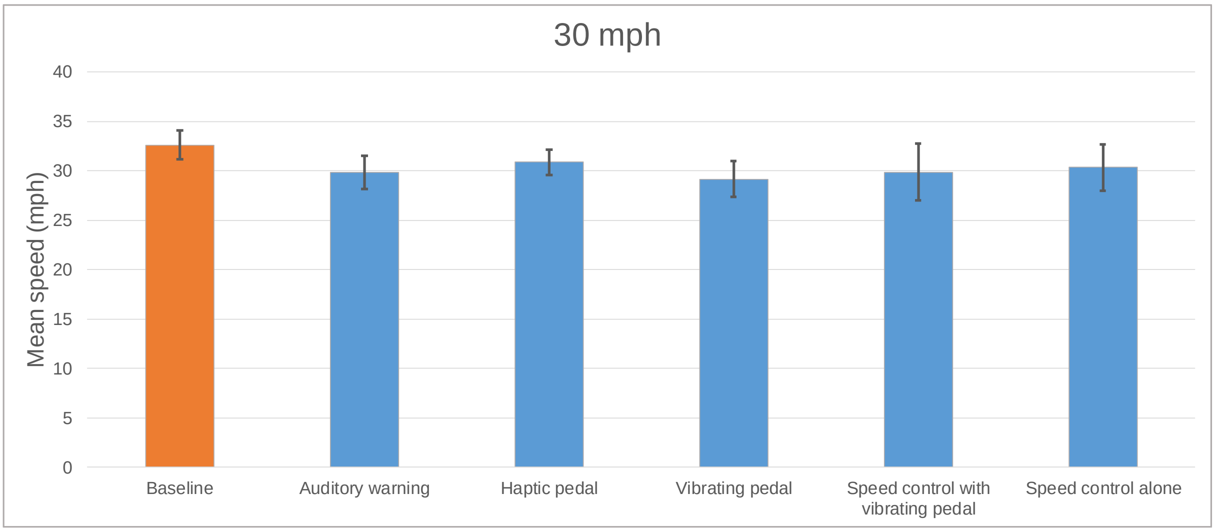

Figure 4: Mean speed by condition on 30 mph road sections

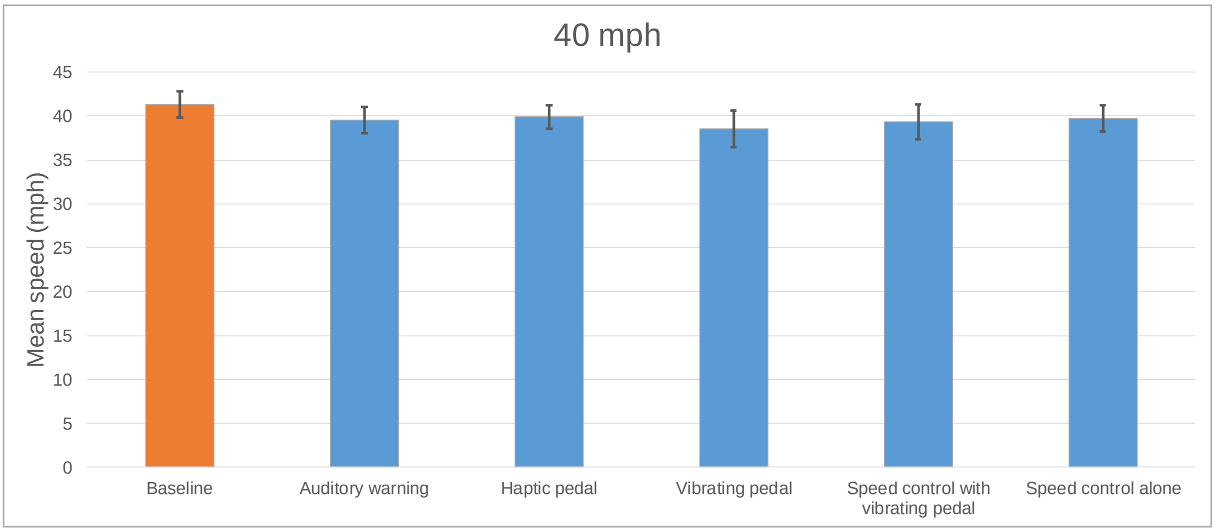

Figure 5: Mean speed by condition on 40 mph road sections

The mean speeds for the 40 mph sections are shown in Figure 5. Post hoc tests indicated that only the Vibrating Pedal condition produced speeds that were lower than the baseline.

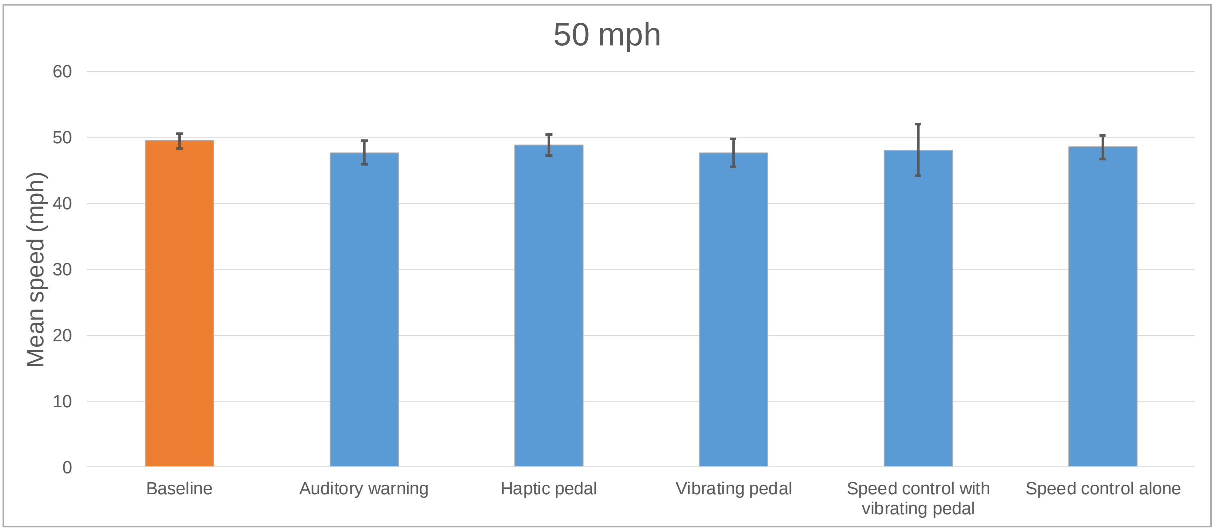

Figure 6: Mean speed by condition on 50 mph road sections

Mean speeds for the 50 mph sections are shown in Figure 6. Post hoc tests (Tukey's) indicated that none of the ISA conditions produced speeds that were significantly lower than the baseline. The same like of significant change was observed for the 60 mph road sections, shown in Figure 7.

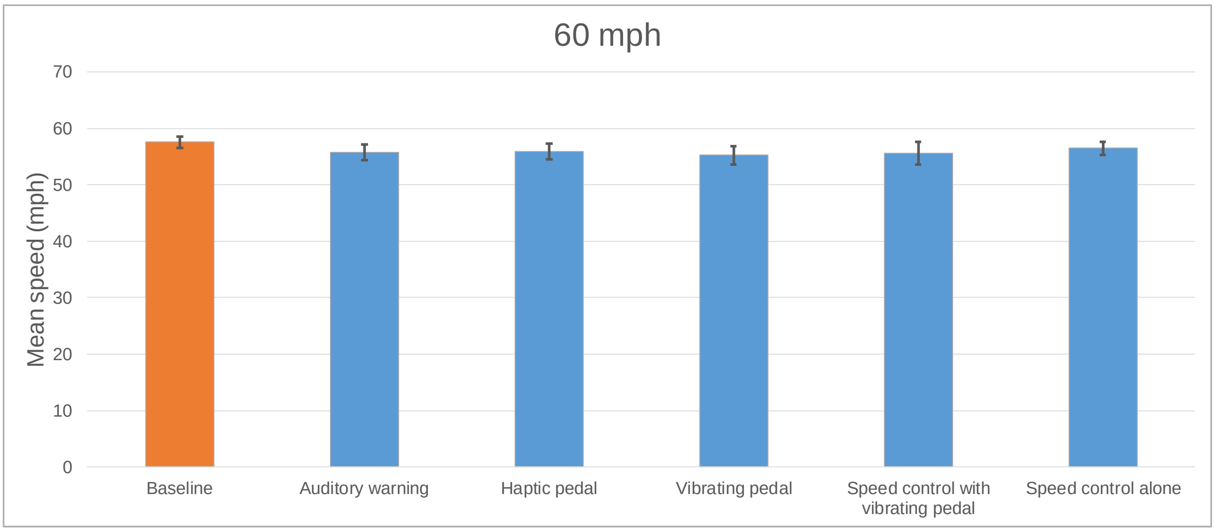

Figure 7: Mean speed by condition on 60 mph road sections

Figure 8 shows mean speeds for the 70 mph road sections. Once again the post hoc tests indicated no statistically significant change.

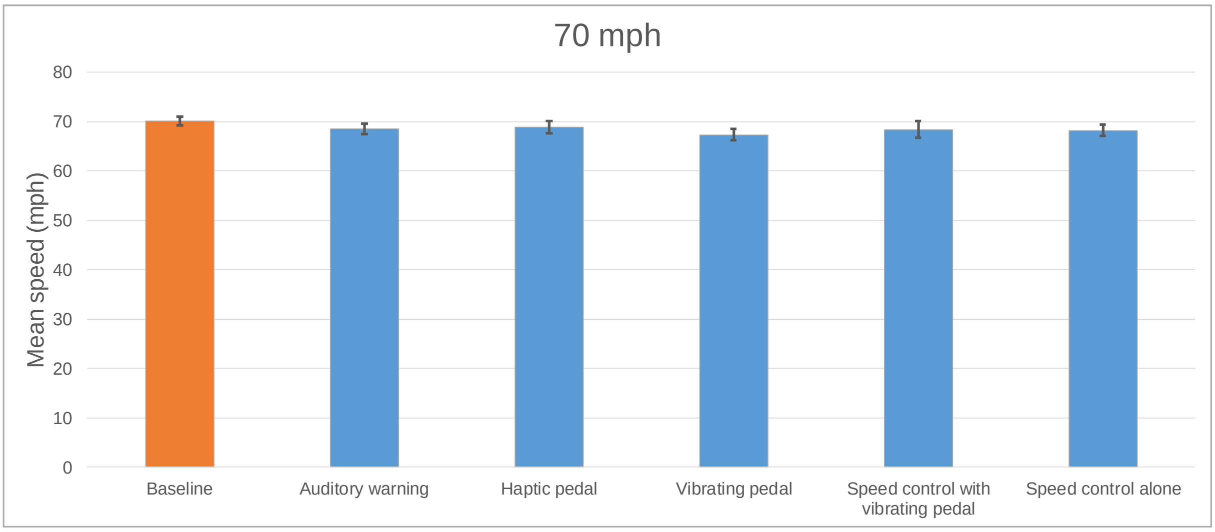

Figure 8: Mean speed by condition on 70 mph road sections

Figure 9 shows the overall mean speed on the entire road. While the speeds with all of the ISA systems appear to be lower than the baseline speeds, post hoc analysis showed no significant differences. Once again, it should be noted that the experiment was conducted with UK drivers, who generally tend to be compliant with speed limits.

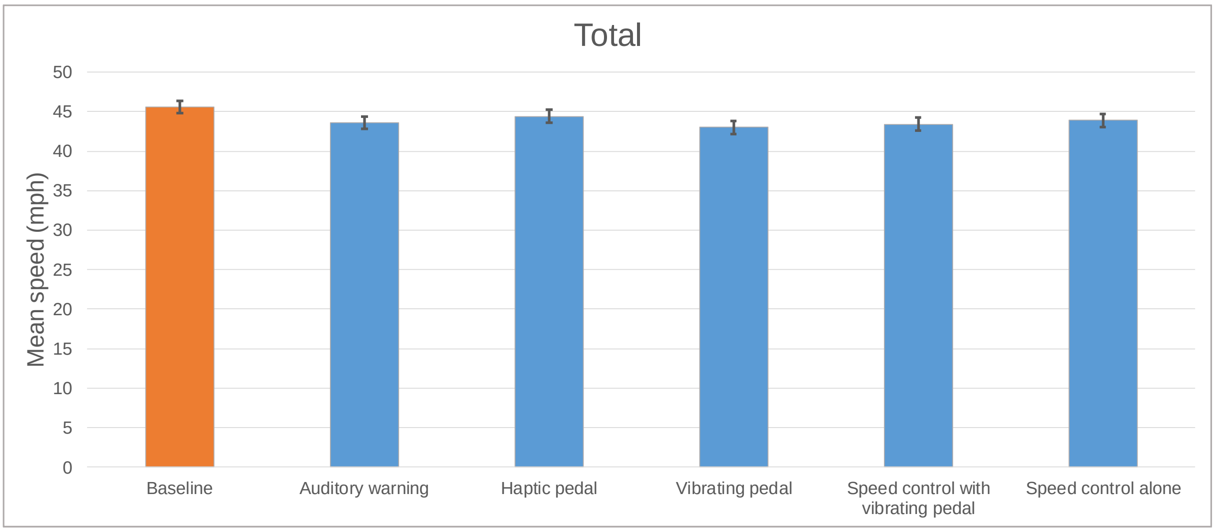

Figure 9: Overall mean speed by condition

3.2 Questionnaire responses

As indicated earlier, participants completed a set of questionnaires following each drive with a version of ISA. They also completed a questionnaire on workload in the baseline (no ISA) condition to permit comparison with workload when driving with ISA. These questionnaires are provided in the appendix, and include the definition of each scale as provided to the participants.

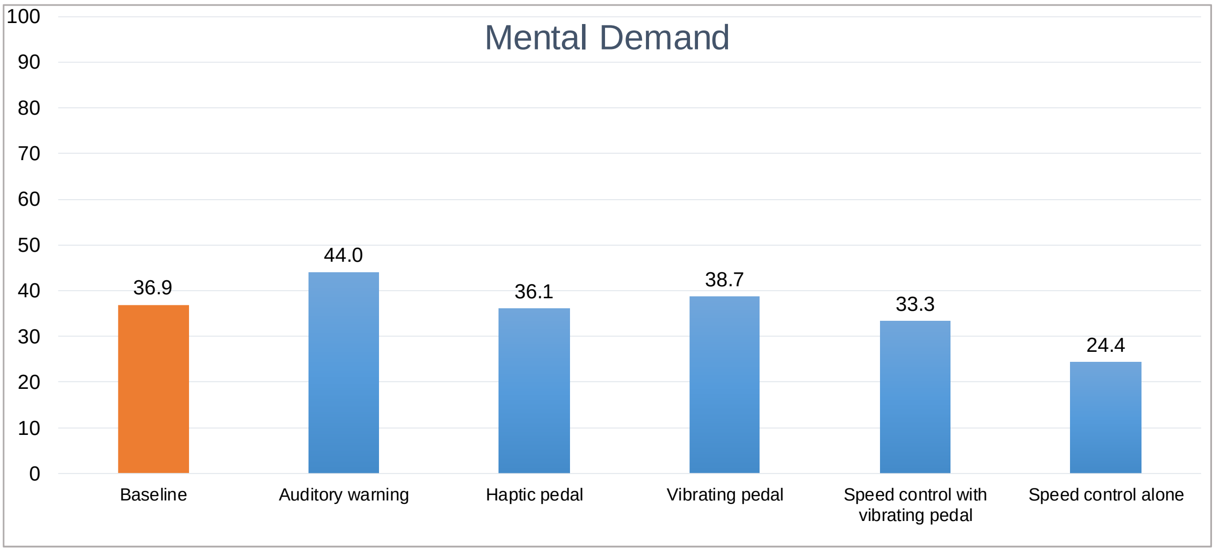

Figure 10: NASA-TLX mental demand

The mean scores on the mental demand component of NASA-TLX, which taps into the "thinking" component of the driving task, are shown in Figure 10. Although there are indications of higher scores with ISA, the Tukey post hoc test indicated no significant differences against the baseline and no differences between the various ISA conditions. The same finding of no significant differences applies to Physical Demand which taps into the physical effort of driving. The results are shown in Figure 11, although there is an indication that the Haptic Pedal required slightly more effort.

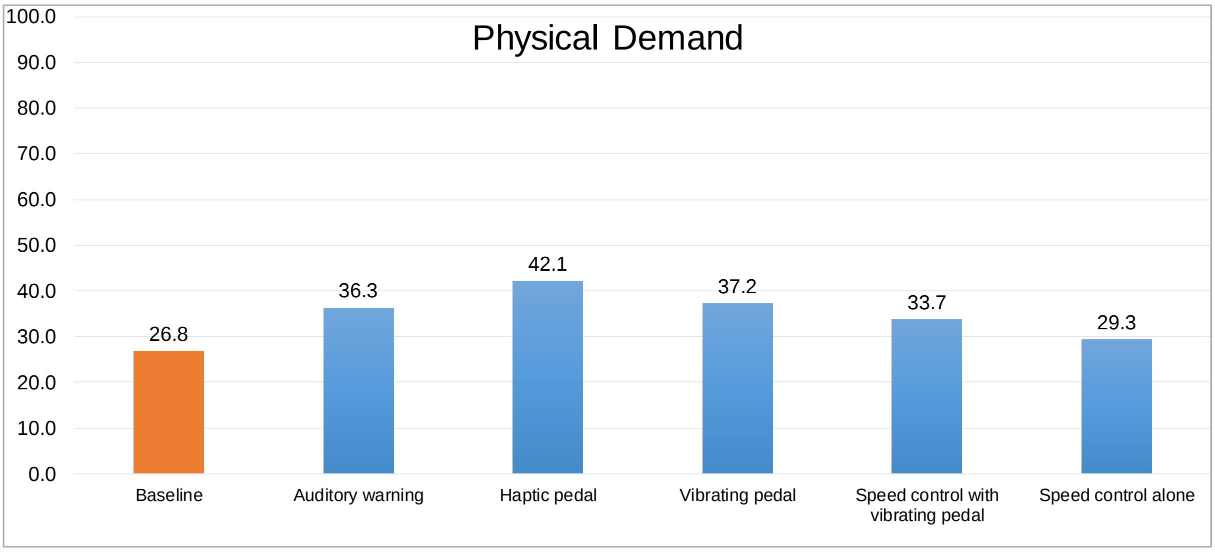

Figure 11: NASA-TLX physical demand

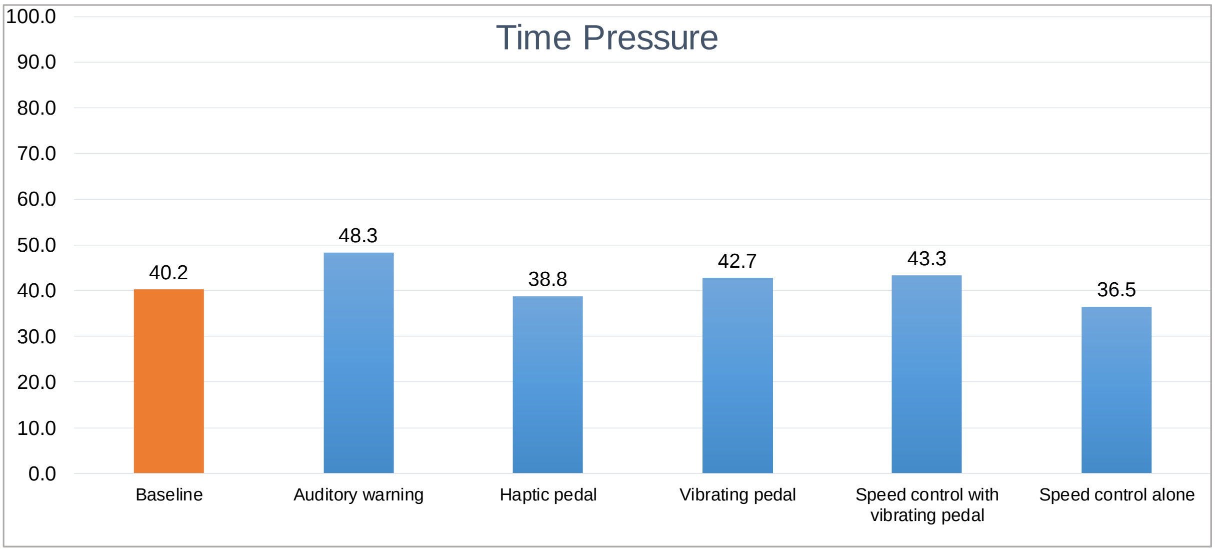

Figure 12: NASA-TLX time pressure

The results for Time Pressure are displayed in Figure 12. Here the drivers were asked whether they felt that they had enough time to adequately perform the driving task. Once again there were no significant differences, although there is an indication that the Auditory Warning induced a great feeling of time pressure. The scores for Performance are shown in Figure 13. Here the participants were asked to rate how satisfied they were with their performance in achieving the goals of the driving task. The Haptic Pedal induced the most positive scores, but once again none of the differences are significant.

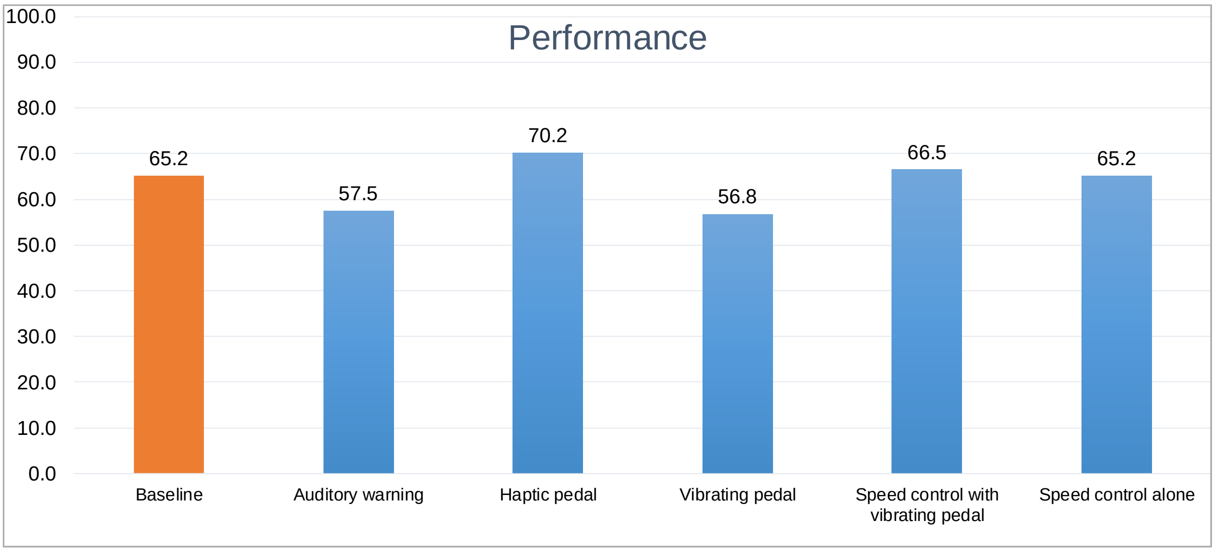

Figure 13: NASA-TLX performance

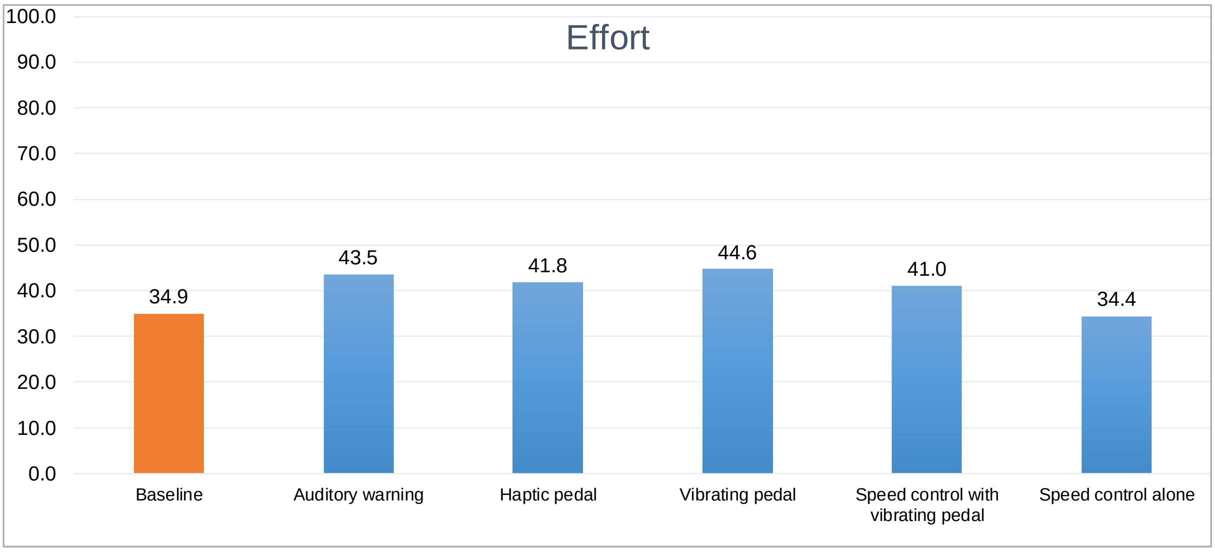

Figure 14: NASA-TLX effort

The mean scores for Effort, which asked the participants to rate how hard they had to work (mentally and physically) to achieve their level of performance in each drive, are shown in Figure 14. There were no significant differences against the baseline, nor between the systems. The results for the Frustration component of NASA-TLX are shown in Figure 15. This asked the participants to rate how insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent they felt while driving. Here the mid-point with a score of 50 is neutral. Scores below 50 indicate positive (non-stressful) feelings; scores above 50 indicate negative (stressful) feelings. Here the Vibrating Pedal was scored significantly worse than the Baseline and was also significantly worse than Haptic Pedal and Speed Control Alone. Apart from Auditory Warning and Vibrating Pedal Alone, the ISA systems were scored as not being stressful.

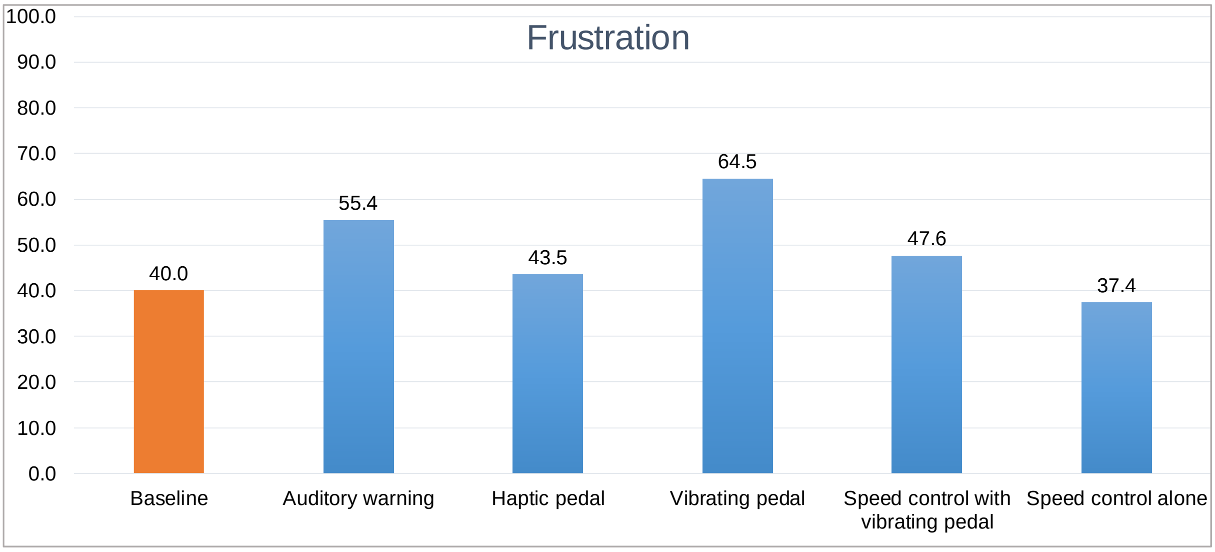

Figure 15: NASA-TLX frustration

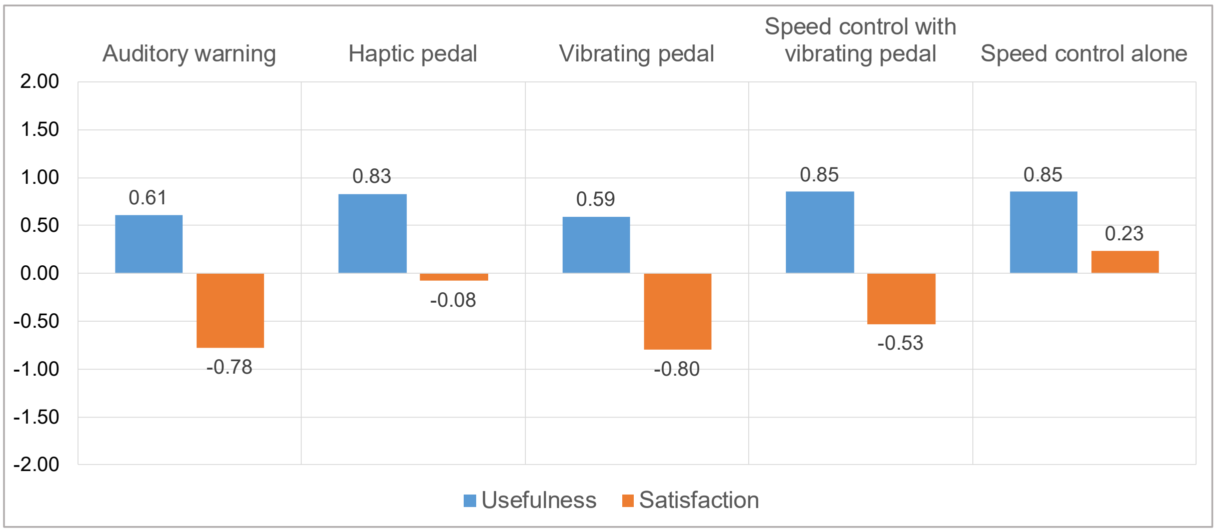

Figure 16: van der Laan Usefulness and Satisfaction

Figure 16 displays the Usefulness and Satisfaction scores for each of the ISA systems. The relevant questionnaire can be found on page 7 of the Appendix. The procedure to reduce the nine scales to the two factors of "Usefulness" and "Satisfaction" is as follows:

1. Convert the categories (left to right) to scores of +2 to −2 (where + is positive)
2. Invert the scores for items 3, 6 and 8 (these items have the positive side deliberately inverted)
3. Usefulness is the mean of 1, 3, 5, 7 and 9; Satisfaction is the mean of 2, 4, 6, 8

Thus Usefulness examines whether the participants felt they needed each of the ISA systems, while Satisfaction examines whether they found each ISA system to be pleasant and desirable. Usefulness was rated somewhat positively, indicating that drivers see value in ISA support. Post hoc analysis (Tukey's) showed no significant differences between the systems for Usefulness. Satisfaction on the other hand was generally negative. Post hoc analysis showed that Auditory Warning and Vibrating Pedal were both rated worse than Speed Control Alone.

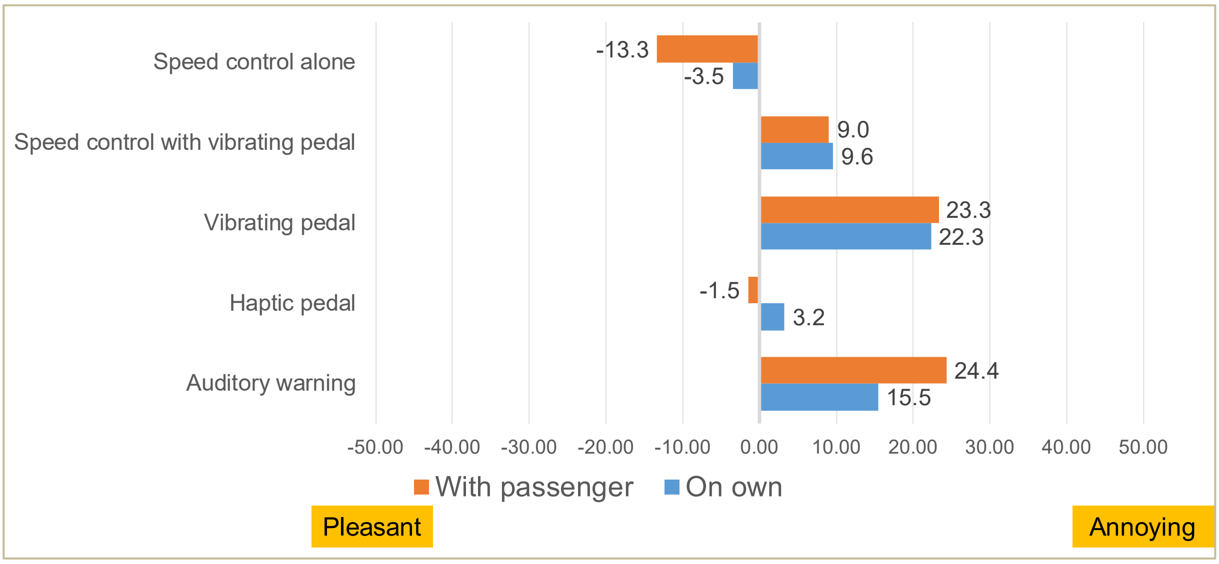

Figure 17: Pleasantness/Annoyance

Figure 17 shows the rating on the Pleasant/Annoying questionnaires. Speed Control Alone was rated as the most pleasant system, and Vibrating Pedal and Auditory Warning as the most annoying. It can be observed that there are some substantial differences between the ratings when performed as if driving alone and the ratings as if driving with a front-seat passenger. Speed Control Alone is rated as more pleasant when having a passenger, perhaps because it is not detectable by a passenger. By contrast, Auditory Warning is rated as substantially more annoying when driving with a passenger, no doubt because, with this HMI, a passenger can detect that a driver is receiving a warning from a driver assistance system. For both of these systems, paired-sample t tests confirmed that the differences are statistically significant ($p \leq 0.05$).

4. Conclusions and recommendations

In many ways, the subjective data obtained by means of the questionnaires provide more insights than the objective data on speed compliance. The drivers were generally quite compliant in the baseline situation, and performance with the various ISA systems was rather similar, although the Vibrating Pedal HMI tended to be the most effective in terms of promoting speed compliance, probably because the vibration was continuous during all the time that a driver was exceeding the speed limit.

The same Vibrating Pedal system produced the highest score on Frustration with NASA-TLX. This is probably a counterpart to its effectiveness, i.e. the drivers noticed that it slowed them down. Not surprisingly, the Haptic Pedal was rated the highest on Physical Demand.

The ratings on annoyance deserve special attention. If a driver assistance system is considered to be unpleasant or annoying, it will very likely be switched off. The overall effectiveness of an ISA system will be the combination of its direct impact on speeding and drivers' willingness to leave it enabled. The ratings on annoyance when driving with a passenger should be particularly noted. Drivers will not be content to use a system that singles them out in the perception of their passengers as receiving a vehicle-generated warning, as is the case with Auditory Warning.

These findings would suggest that neither the Auditory Warning nor the Vibrating Pedal (without Speed Control) are good choices for ISA HMI. Equally, the Vibrating Pedal (without Speed Control) was also rated negatively on annoyance, probably because, without the speed control function, it was hard for the drivers to control the accelerator pedal to prevent the vibration. It should be noted that the most positive rating on the Pleasant/Annoying scale was for Speed Control Alone, followed by the Haptic Pedal and Speed Control with Vibrating Pedal. Each of those three systems can therefore be considered to have reasonable acceptance.

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van der Laan, J.D., Heino, A. and de Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. Transportation Research Part C: Emerging Technologies, 5(1): 1-10.

Appendix: Questionnaires

To request a copy of the questionnaires used for this study please contact Professor Oliver Carsten: O.M.J.Carsten@its.leeds.ac.uk