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Simulation of accident risk displays in motorway driving with traffic

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The study used a vehicle-based driving simulator to evaluate two graphical displays, one showing risk probability in terms of safety margin (Time Headway, TH), and one showing risk severity in terms of Kinetic Energy (KE). Twenty-seven subjects were randomly allocated to one of three experimental conditions: Control, TH, and KE. Subjects undertook three driving tasks (ABA design). For the second driving task in the TH and KE conditions, subjects drove in the presence of their respective feedback displays. Measures of TH and KE levels were taken, as well as subjective measures of risk and task loading. It was found that the KE display was more effective than the TH display in reducing the proportion of time subjects spent at short headways. The KE display was also effective in reducing the proportion of time subjects spent at high speed. The KE display appeared to affect the perception of risk (severity of potential accidents). It was concluded that further research evaluating displays that combined the positive effects of both parameters within a single representation display is needed.

1. Introduction

There is evidence to suggest that drivers tend to consistently underestimate the risks involved with driving, and overestimate their driving skills and capabilities (Dejoy 1992, Elander et al. 1993). These tendencies may go some way to explaining why some drivers engage in high-risk driving behaviours such as tailgating or driving at excessive speed (Evans and Wasielewski 1983). This is particularly true for drivers with low experience because they have learnt the necessary motor skills to drive a car, but have not yet learnt the perceptual and judgement skills to maintain safe distances, recognize potential hazards, and avoid them (Aphaloe et al. 1987).

Modern in-vehicle technology now makes it possible to present safety-relevant information to drivers about the risk associated with driving style. Risk parameters could be graphically displayed to the driver to represent the level of risk and their rate of change contingent upon driving performance. Owens et al. (1993) argue that the primary challenge for driver support systems is to take a ‘user-centred’ approach and provide drivers with information that will reduce their risky driving behaviour. The user-centred approach takes explicit account of the fact that humans may not be sensitive to the determinants of accident risk and may not be able to judge what

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levels of risk are still acceptable. There are general indicators of driving style that have been linked to accident risk, namely (1) speed choice, and (2) adopted headway.

(1) *Speed choice.* Choice of driving speed has emerged as a critical determinant of crash involvement. Wilson and Greensmith (1983) compared 100 crash-involved and crash-free drivers who drove a 50 km route in an instrumented car. They found that crash-involved drivers recorded higher speeds on clear roads, and that drivers involved in crashes caused specifically by excess speeds reported driving faster than other drivers. Nilsson (1982) has examined changes in crash rates and casualties associated with changing speed limits and travelling speeds in Sweden. Both the rate of accidents and the rate of injury increased proportionally with the relative increase in average speed from previous values.

(2) *Headway choice.* Another facet of driving style that can lead to increased risk is the tendency to leave short headway distances from the vehicle in front (Baxter et al. 1990). Colbourn et al. (1978:2) discussed the relationship between speed choice and headway and stated that ‘drivers will maintain headways greater than necessary at low speeds but will tend to follow too closely at higher speeds’. Evans and Wasielewski (1983) studied video footage of 2576 vehicles of Michigan registration and the associated driver characteristics and compared these with state records of accident involvement and traffic violations. They found that those drivers following other freeway traffic at less than 1 s time headway had higher accident rates. These ‘risky’ driving style drivers also had a higher rate of traffic violations (see also Rajalin 1994). Evans and Wasielewski (1983) concluded that drivers who had been involved in accidents or cited for violations had a riskier everyday driving style than drivers who had never had accidents or violations.

1.1. *Propositions for risk information*

Driver support systems could be developed to represent the risk associated with fast speed and short headway driving. The development of accident risk displays could be based on the display of information relating to driving style affecting (1) safety margin (accident probability), and (2) accident severity.

(1) *Risk as accident probability.* Conceptually, the greater the temporal safety margin, the more time within which to successfully engage an accident avoidance manoeuvre (cf. Brown 1990), thereby increasing the probability of avoiding an accident. Time headway (TH) is one measure of the temporal safety margin between successive vehicles. TH is defined as the time for a following car at a fixed speed \( s \) to traverse the distance \( d \) to a lead vehicle: 

\[
TH = \frac{d}{s}.
\]

The shorter the TH (for a given speed), the less probable that an accident could be avoided.

Note that TH is used here as an indicator of accident probability rather than time-to-collision (TTC). A TTC display would suggest that there was no chance of an accident whenever the relative speed is zero regardless of the temporal separation between cars. Intuitively (as well as practically), there is an inherently greater risk of an accident when following a car at a constant
speed of 120 mph [193 kph] with a TH of 1 s, than there is at a TH of 10 s because there is less temporal separation within which to successfully avoid an (unexpected) hazard. Similarly, there is an inherently greater risk of an accident when following a car at a constant headway of 2 s while both cars are travelling at a speed of 120 mph than when travelling at 10 mph [16 kph], in this case because the greater stopping distance required at the higher speed may not be safely accommodated by the existing temporal separation. Yet, a TTC display would indicate the same zero level of risk in each of these situations.

(2) Risk as accident severity. The severity of an accident is related to the square of the speed, which is indicative of the amount of kinetic energy (KE) dissipated in the crash (Nilsson 1982, Miltner and Salwender 1995). Owens et al. (1993) contend that this relationship between speed and crash severity may not be apparent to drivers. Owens et al. (1993) suggest that this lack of awareness is responsible for the tendency of many drivers to drive too fast for their current driving conditions. Based on this supposition, Owens et al. (1993) discuss the potential benefit of providing drivers with an energy meter (E-Meter), which graphically displays to drivers the KE state for their current speed relative to the standard of a survivable fixed-barrier crash at 30 mph (Risk Unit, RU). On this basis, 1 RU would correspond to the base referent of 30 mph [48 kph]. In sequence, 2 RU would represent twice the energy level of the 30 mph referent corresponding to a (fixed barrier) impact at 42 mph [68 kph]; 3 RU would represent three times the energy level of the 30 mph referent corresponding to an impact at 52 mph [83 kph]; 4 RU would represent four times the energy level of the 30 mph referent corresponding to an impact at 60 mph [97 kph]; and 5 RU would represent five times the energy level of the 30 mph referent corresponding to an impact at 67 mph [108 kph]. To date however, the suggestion that awareness of kinetic energy and crash survivability are significant for safe driving remains to be tested empirically.

1.2. The purpose of the present study
The study was undertaken to evaluate the effects of prototype displays designed to convey the accident risk assumed with current driving behaviour. The proposed risk displays were evaluated in terms of the effect on driving behaviour and subjective perceptions of risk. The evaluation was conducted within a fully interactive driving simulator. The task for subjects was to drive the vehicle and interact with other traffic in a manner that they perceived to be safe. The primary measures were: (1) the mean and variation of driving performance (speed and time headway); and (2) exposure within each unit interval of the KE and TH display scales. Subjective measures of risk and task loading were included to explain subject behaviour. Figure 1 presents the design of the study. Comparisons were made between display types and a control condition (between-subject—Comparison 1) as well as within each condition across successive trials (within-subject—Comparison 2). The provision of accident risk information was hypothesized to prompt a shift away from a ‘risky’ driving style. This would be demonstrated by a shift toward lesser exposure to high risk, and an expected mean decrease in risk (and reduced variation).
2. Method

2.1. Subjects
Young and low-experienced male drivers were recruited. The sample consisted of twenty-seven male drivers between the ages of 22 and 33 years ($M = 25$ years) who all held a full British driving licence. On average, this sample had reportedly been driving for approximately 5 years with an estimated annual mileage of approximately 7500 miles [12100 km]. All subjects undertook three driving trials in a single treatment condition. No differences were found between the conditions for age, number of years driving, and number of miles driven annually. All subjects had (corrected) near and far visual acuity at 20/30 or better.

2.2. Driving simulator
This simulation was controlled by a Pentium PC and projected by a Sony Superdata BX Colour Projector onto a 13.5 × 7.9 ft screen [4.11 × 2.41 m]. Viewed from a distance of 16.7 ft [5.09 m], the visual angle of the projected scene was approximately 45 × 25°. The driving simulator depicted a simple line graphic view of a two-lane carriageway (UK configuration) from the perspective of the driver at a calculated eye height of approximately 40 in. [1.02 m]. The frame rate was 10 Hz at a resolution of 640 × 350 pixels. The simulator was interfaced to a Ford Granada. Steering, accelerator and braking actions upon the vehicle were reproduced in the simulation. The simulator gave speed feedback through the vehicle speedometer. The vehicle interface and specified data channels were sampled on-line at a rate of 10 Hz. The vehicle and the screen were enclosed in a blackened room to limit stray light. A constant taped engine noise was played during sessions to simulate road noise and isolate the subject from outside noises. A handsfree intercom linked the experimenter to the subject for verbal instruction and verbal data.

2.3. Simulated traffic environment
The simulated traffic environment was based on eight core scenarios (table 1) referenced to a starting position for the subject in the left (slow) lane of the simulated
two-lane dual carriageway. The scenarios were intended to evoke interaction with traffic and traffic hazards.

Multiple occurrences of these core scenarios were combined in seamless links to create different series of traffic events. A practice series was created for the familiarization session. Three test series were created for the experiment trials comprising 20 events. These test series took approximately 20 min of continuous driving to complete at an average speed of 70 mph [113 kph].

Each of the test series for the experimental trials had four events (2, 4, 5, 8) which remained in the same ordinal position (3, 10, 15, 18) during which verbal estimates of risk were obtained from subjects. Apart from these standard event placements, the order of events for the three test series were different. The three test series were counterbalanced across experiment trials within a condition.

2.4. Risk display configuration

A colour LCD measuring 118 x 86 mm was used to present the accident risk displays. This LCD connected to a second Pentium PC, which ran the graphics program that generated the accident risk displays. This PC was linked to the simulator to provide real-time feedback of time headway (s) and kinetic energy (RU) from the risk displays. The LCD was positioned inside the vehicle on the dashboard, slightly offside to the left of the driver. This positioning was adopted to effect a head-up display orientation. An illustration of the (kinetic energy) risk display is shown in figure 2. The display had a dark background colour that was lightened to a bright colour as the display region was activated.

Both the TH and KE risk displays were based on the sectioned bar display used by Graham and Hirst (1994) and by Carter et al. (1995). The displays were designed so that they presented their feedback information incrementally across a standard graduated scale comprised of five coloured sections: the first two sections were green, the third amber, and the final two red. The displays indicated progressively from left to right as headway decreased (TH display) and as energy increased (KE display). This progressive nature of the displays’ illumination was intended to dynamically demonstrate (1) the current driving risk status, and (2) the rate of change of the driving risk status. (By using the same scale format for both displays, any effect of display type could be attributed to the information content of the displays rather than differences in display configuration. However, the need to maintain the same direction of scale movement for the two scales meant that the scale unit ordering was in opposite directions.)

<table>
<thead>
<tr>
<th>Table 1. Traffic event core scenarios.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Single car at 40 mph [64 kph] in left lane.</td>
</tr>
<tr>
<td>3. Left car at 40 mph [64 kph], right car at 50 mph [80 kph].</td>
</tr>
<tr>
<td>4. Left car at 20 mph [32 kph], right car at 30 mph [48 kph].</td>
</tr>
<tr>
<td>5. Left car at 50 mph [80 kph], right car at 30 mph [48 kph].</td>
</tr>
<tr>
<td>7. Single car from behind in right lane, moving to left lane (overtake subject), and slow to 20 mph [32 kph].</td>
</tr>
<tr>
<td>8. Car in left lane at 30 mph [48 kph], second car ahead in right lane at 50 mph [80 kph] moving to left, and slowing to 30 mph [48 kph]</td>
</tr>
</tbody>
</table>
2.4.1. Safety margin (TH) display: The TH display presented information about the probability of an accident in terms of the TH between the subject vehicle and the lead vehicle. The scaling for the TH display corresponding to the five sections was coded in 1 s increments for 5 to 0 s, moving left to right from low- to high-risk. The two green sections were bound by 5 and 3 s, the amber section by 3 and 2 s, and the two red sections by 2 and 0 s. The correspondence of this scaling to the colour coding of the display was comparable to the findings of Carter et al. (1995), Colbourn et al. (1978), Rockwell (1972), and the UK Department of Transport recommended ‘safe’ following headway. A time headway below 2 s was coded as the high-risk threshold.

2.4.2. Accident severity (KE) display: The KE display represented the severity of an accident in terms of the kinetic energy of the simulator vehicle. The scaling of the display was based upon 1 Risk Unit (RU) equivalent to the energy dissipated in a survivable crash at 30 mph [48 kph] against a fixed barrier (Owens et al. 1993). To achieve the same numerical scaling as the TH display, a 5-point scale based upon unit multiples of 1 RU was calculated. (Note: although only 5 points on this display were displayed, the behaviour of the driver was recorded on a full 10 points for analysis.) The scaling for the KE display corresponding to the five sections was coded in 1 RU increments from 0 to 5 RU, moving left to right from low- to high-risk. This scaling represented speed values of 0 mph, 30 mph, 42 mph, 52 mph, 60 mph and 67 mph, respectively [0, 48, 67, 84, 97, 108 kph]. The two green sections were bound by 0 and 2 RU, the amber section by 2 and 3 RU, and the two red sections by 3 and 5 RU. Although the display did not display scale values greater than 5 RU points in order to keep the display range similar to the TH display, KE data was recorded up to 10 RU, which represented the maximum vehicle speed of 95 mph [153 mph].

2.5. Instructional materials
The subjects received detailed instructions on aspects of the risks involved in driving, and how these are related to driving behaviour. This was necessary so that subjects
fully understood how behavioural aspects of driving style affected accident risk. More specifically, because of the novel nature of the risk displays, it was necessary to fully brief subjects on: (1) the meaning of the risk measured by the displays, and (2) the significance of the criteria upon which the display was formatted. For this purpose, a detailed instructional package was devised.

2.5.1. Risk instruction: The first section of an instruction package discussed how specific driving styles relate to accidents. The first section explained that the probability of being involved in an accident is related to the time headway that drivers leave between themselves and lead vehicles in traffic. The information also explained that the severity of an accident is related to the amount of kinetic energy that is dissipated in it, which is proportional to the square of the speed of the vehicle. This section was included for subjects in all conditions. The second section described the purpose of the study and concluded with a summary section. The stated purpose of the study was to develop and evaluate new displays that convey information about the risks of potential accidents while driving. Subjects were informed that the study would investigate the effects these displays have on driving and assess their reactions to these displays. It was explained that they would be assigned to one condition, with either form of display, or to a control condition without a display.

2.5.2. Task instructions: All subjects also received a set of task instructions. The instructions explained to subjects that they would be required to drive for three, 20-min periods during which they should drive as they would normally on a dual carriageway with a 70 mph speed limit [113 kph]. Subjects were told to interact with other traffic. Subjects were explicitly instructed to treat traffic as it if were a real and potential hazard. They were told to drive at a speed and headway that they perceived to be safe. Subjects were instructed on the types of questionnaire to be administered and the requirement to provide verbal ratings of risk at various points during the driving task. In the two risk display conditions, the task instructions contained illustrated instruction of the meaning and significance of the respective risk display.

2.5.3. Confirmation of instruction: Subjects were given a formally administered set of questions to verify their comprehension of the instructional package and task instructions with respect to the risk display(s) and the driving task. A separate coloured graphic sheet was created for each risk display. The first section contained diagrams of the relevant display at various informative states and how these related to the vehicle status. The second section contained five questions related to how the displays worked and what information they presented. These questions were to be answered verbally to the experimenter as a check to ensure that subjects had fully understood the explanatory information about the new displays.

2.6. Experimental design
Figure 1 illustrates the full design of the study. The study was comprised of two independent variables: display condition (control, time headway, kinetic energy) and trial (A, B, C). Display condition was treated as a between-subject factor and trial was treated as a within-subject (repeated measure) factor. Thus, the complete design of the study was a mixed factor 3 × 3 design. This mixed design provided both a
within-subject (trial) and between-subject (display condition) comparison to test the effect of the risk displays.

2.7. **Dependent variable measures**

2.7.1. **Driving risk:** Time headway and kinetic energy were collected as raw values online by the simulator at a rate of 10 Hz. After each trial, the simulator saved the raw data file as well as a post-processed file with the raw data converted to the percentage of driving time occupied in each half scale unit on both the TH and KE scales. The time percentage data for TH (over the 5 scale units) and KE (over a 10 scale unit range rather than the 5-point scale used in the display) were treated as separate dependent measures. Half-scale units were used to increase the resolution of the analysis of the behaviours.

2.7.2. **Subjective risk:** At various prescribed points in the series of traffic scenarios (ordinal positions 3, 10, 15, 18), subjects were asked to provide verbal ratings of risk over the vehicle intercom. These risk ratings required subjects to state the number that most accurately represented their risk at that time on the following 7-point scale with higher values representing greater perceived risk (adapted from Heino *et al.* 1992). A card with this scale was affixed to the dashboard for reference by the subject. Four ratings were obtained in each trial. These were averaged to obtain an overall measure of perceived risk:

- No perceived risk 1 – 2 – 3 – 4 – 5 – 6 – 7 Unacceptable risk
- 1 = No perceived risk
- 2 = Very little risk
- 3 = Little risk
- 4 = Intermediate risk
- 5 = Much risk
- 6 = Very much risk
- 7 = Unacceptable risk

After each trial subjects also completed an *ad hoc* questionnaire devised for this study to measure subjective risk. It was comprised of five questions relating to perceptions of (1) safety, (2) cautiousness, (3) the probability of an accident, (4) the severity of an accident, and (5) overall risk. Responses were indicated by placing a mark on a line anchored by bipolar adjectives. Higher scores were indicative of greater perceived risk.

2.7.3. **Mental workload:** The NASA RTLX was chosen as a standard measure of task workload (adapted from Byers *et al.* 1989). This required subjects to rate the task in terms of mental demand, time pressure, operator performance, effort, frustration, and physical demand. These items were responded to by an indication on a line anchored by bipolar adjectives. A total score was calculated by averaging the individual scale values, such that higher scores were indicative of greater workload.

2.8. **Procedure**

Upon arrival at the test site, subjects were shown the driving simulator and read a set of instructions explaining how to use the simulator. Subjects were then seated and
carefully read the instructional package followed by the task instructions for their assigned condition. Subjects were queried on their comprehension of this information. The experiment commenced once the experimenter was satisfied that the subjects had understood the information.

After the briefing stage, subjects were seated in the vehicle and the driving simulator was explained. Subjects were then given a 15 to 20 min familiarization period using the simulator with a practice series of traffic events. On completion of the familiarization period, the experimenter stopped the simulation. The subject was then asked to read and complete a statement of informed consent.

The experimental session comprised three test trials (figure 1). For the second trial (B) of the two risk display conditions, the LCD screen was turned on and the respective display initialized. Each trial lasted approximately 20 min and involved a series of 20 traffic events.

The experimenter told the subject over the intercom that they could begin driving when they saw the road ahead, then the simulation was initiated. The experimenter traced progress through the event series using an external monitor and asked the subject for the verbal risk assessments over the intercom at predetermined periods. On completion of a trial, the experimenter stopped the simulation and requested the subject to then read and complete the subjective risk and mental workload questionnaires. This process was repeated for the three trials of each condition. Once all three trials had been completed, the subject exited the simulator and completed the Display Evaluation Questionnaire. The subject then had a vision test for near and far acuity (Keystone VSII Vision Screener) and was paid £10 sterling (approximately $15 US) for participation.

3. Results

3.1. Exposure data

The TH and KE data were expressed as a percentage of total task time occupied within each half-scale interval. The TH and KE exposure data were subjected to both descriptive and inferential statistical analysis. The 0.0–0.5 s and 0.0–0.5 RU intervals were omitted from the analysis due to insufficient data (i.e. too few data points were obtained in this region for a statistical analysis and meaningful interpretation). The 4.5–5.0 s interval was also excluded because it contained all occasions with a null headway when no lead car was present or ahead of the subject vehicle.

The distribution of exposure data for subjects in each scale interval tended to be skewed. There was also a lack of homogeneity of variance between scale intervals. Thus, comparisons were made with appropriate non-parametric tests. For this reason it was necessary to forego tests of interaction terms for the exposure data. As shown in figure 1, separation comparisons were made of the between-subject effect of display type in trial B (comparison 1) and for the within-subject effect across successive trials (comparison 2). It was expected that the possible increase in the family-wise error rate arising from the number of tests for each scale interval would be offset by the conservative power of non-parametric tests (Siegal and Castellan 1988).

3.1.1. Time headway: Figure 3 illustrates the mean exposure for time headway within each half-scale interval for each trial in the (a) control, (b) TH display, and (c)
KE display conditions.

(1) Comparison 1 (between-subject effect of trial B): Subjects with the KE display had significantly more exposure to open-lane driving in the 4.5 – 5.0 s

Figure 3. Mean headway exposure within half-scale intervals for each trial within the (a) control condition, (b) TH display condition, and (c) KE display condition. (Note: The interval of 4.5 to 5.0 s is not included due to high percentage values that would distort the y-axis range).
interval ($M = 83.2\%$) than did subjects in the control condition ($M = 77.0\%$) [Kruskal-Wallis, KW (2) = 6.00, $p < 0.05$].

(2) **Comparison 2** (within-subject effect): Exposure in the headway interval between 1.6 and 2.0 s was significantly reduced [Freidman test, FR (2) = 6.22 $p < 0.05$] with the KE display (trial B, $M = 1.30\%$) in comparison to before the display was introduced (trial A, $M = 1.72\%$). There appeared to be a residual (learning) effect of the display after its removal in trial C ($M = 1.49\%$). A similar (marginal) trend was observed between 2.1 and 2.5 s ($p < 0.10$). Exposure in the headway interval between 1.1 and 1.5 s was significantly reduced [FR (2) = 6.89, $p < 0.05$] with the TH display (trial B, $M = 0.44\%$) in comparison to before the TH display was introduced (trial A, $M = 0.78\%$). There again appeared to be a residual (learning) effect of the display after its removal in trial C ($M = 0.50\%$). There were no comparable significant ‘safety’ trends within the control condition for any of these noted intervals.

### 3.1.2. Kinetic energy

Figure 4 illustrates the mean exposure for kinetic energy (RU) within each half-scale interval for each trial in the (a) control, (b) TH display, and (c) KE display conditions.

(1) **Comparison 1**: The apparent trend for subjects with the KE display to reduce high-risk exposure and increase low-risk exposure across the RU scale did not reach significance within any interval.

(2) **Comparison 2**: Exposure in the KE intervals of 8.6–9.0 RU, 9.1–9.5 RU, and 9.6–10.0 RU was significantly reduced with the KE display [FR (2) = (6.06, 5.06, 4.67), $p < 0.05$]. As shown in table 2, exposure was less with the display than before its introduction. There was again an indication of a learning effect with the display removed in trial C. There were no comparable significant ‘safety’ trends in the control condition for any of these noted intervals.

In contrast, the TH display resulted in significantly less exposure [FR(2) = 8.00, $p < 0.05$] in the interval of 6.6–7.0 RU (trial B, $M = 7.74\%$) than without the display (trial A, $M = 10.78\%$, trial C, $M = 11.62\%$), but also resulted in significantly *greater* exposure [FR(2) = 5.72, $p < 0.05$] in the higher risk interval of 8.1–8.5 RU (trial B, $M = 1.48\%$, trial C, $M = 1.20\%$) than before the display was introduced ($M = 0.68\%$).

### 3.2. Mean and variation in performance

For each subject, the distributions of time headway and speed data were summarized by the mean and coefficient of variation as measures of central tendency and dispersion. In addition, the 5th percentile time headway value and the 95th percentile speed value were calculated.

For speed choice, each data variable was analysed within a 3 (COND: control, TH display, KE display) × 3 (TRIAL: trial A, trial B, trial C) mixed design. Evidence for risk display effectiveness from the A-B-A design would be in the form of a quadratic trend (Trial B ≠ [Trial A or Trial C] with Trial A ≡ Trial C; ∩ shaped). Thus, the effect of display (COND) was treated as a quadratic polynomial term. Post-hoc analysis of the simple effects for the hypothesized trends was conducted
with the Tukey HSD test modified for the restricted set of hypothesized comparisons (Toohacker 1991). This form of post-hoc analysis does not require a significant interaction term.

For headway choice, the original data set was initially recorded for the purpose of the exposure analysis. To compute summary variables, instances with no car present

Figure 4. Mean kinetic energy exposure in each half-scale interval for each trial within the (a) control condition, (b) TH display condition, and (c) KE display condition.
or no car ahead of the subject car (such as when subject overtakes lead car, and returns to the initial lane in lead position) were assigned a value of zero. These values then accumulated in the exposure data for the time headway interval 4.5 to 5.0 s (4.5+). For this analysis of mean, coefficient of variation, and 5th percentile, it was necessary to reassign default values to these cases. These open-lane cases were awarded a 6 s default value because the effect of a display on increasing time in clear lanes can be construed as a safety advantage with respect to rear-end collisions (in comparison to remaining behind a lead car). Admittedly, since an advantage of open-lane driving is presumed and the value assigned to such cases is arbitrary, reliance on this re-analysis of the time headway data must be tempered. Furthermore, the distribution of the time headway data violated parametric assumption, thereby necessitating non-parametric analyses, for comparison 1 and 2 as in the case of the exposure data (see figure 1).

3.2.1. Mean speed: Figure 5 illustrates the mean speed for the control condition and each display in each trial. There was a marginally significant interaction effect between COND and the quadratic term for TRIAL $[F(1,24) = 2.90, p < 0.07]$. Post-hoc analysis indicated that the mean speed in trial B was lower for subjects with the KE display than for subjects with either the TH display or no display (comparison 1). Moreover, in the KE display condition the mean speed was lower with the display present (comparison 2). In the TH display condition, mean speed increased over successive trials.

3.2.2. Speed 95th percentile: Figure 6 illustrates the 95th percentile speed for the control condition and each display in each trial. There was a significant interaction effect between COND and the quadratic term for TRIAL $[F(1,24) = 6.94, p < 0.001]$. Post-hoc analysis indicated that extreme speeds were slower in trial B for subjects with the KE display than for subjects with either the TH display or no display (comparison 1). Moreover, in the KE display condition, the extreme speed was lower with the display present (comparison 2).

3.2.3. Speed variation: Figure 7 illustrates the coefficient of variation of speed for the control condition and each display in each trial. There was a significant main effect for TRIAL $[F(2,48) = 3.32, p < 0.05]$ such that speed variation generally decreased over successive trials.

3.3. Headway choice
3.3.1. Headway mean: Figure 8 illustrates the mean time headway for the control condition and each display in each trial.

(1) Comparison 1: The mean time headway for subjects with the KE display ($M = 5.16$ s) was marginally larger $[KW(2) = 5.52, p < 0.06]$ than for subjects with either the TH display ($M = 4.97$ s) or no display ($M = 4.96$ s).

(2) Comparison 2: There were no significant effects across trials in any condition.

3.3.2. Headway 5th percentile: Figure 9 illustrates the 5th percentile time headway for the control condition and each display in each trial.

(1) Comparison 1: The 5th percentile time headway for subjects with the TH display was significantly less ($M = 0.82$ s) than for subjects with either the
KE display \((M = 1.03\ s)\) or no display \((M = 1.02\ s)\) \([\text{KW}(2) = 6.90, p < 0.05]\).

(2) **Comparison 2:** The 5th percentile headway with the TH display (trial B, \(M = 0.82\ s\)) was significantly less than before its introduction (trial A, \(M = 1.07\ s\)) \([\text{FR}(2) = 6.22, p < 0.05]\). There is also an indication of a learning effect in trial C \((M = 0.93\ s)\). The *opposite* trend of larger headway in trial B in the control condition was marginally significant \([\text{FR}(2) = 5.64, p < 0.06]\). There was no significant `safety` effect for the KE display.

3.3.3. **Headway variation:** Figure 10 illustrates the coefficient of variation of time headway for the control condition and each display in each trial.

(1) **Comparison 1:** The variation in time headway for subjects with the KE display \((M = 0.33)\) was marginally less than for subjects with either the TH display \((M = 0.38)\) or no display \((M = 0.37)\) \([\text{KW}(2) = 5.76, p < 0.06]\).

(2) **Comparison 2:** There were no significant effects across trials in any display condition.

<table>
<thead>
<tr>
<th>Risk units</th>
<th>Trial A (%)</th>
<th>Trial B (%)</th>
<th>Trial C (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.6–9.0</td>
<td>1.84</td>
<td>0.80</td>
<td>1.11</td>
</tr>
<tr>
<td>9.1–9.5</td>
<td>0.74</td>
<td>0.34</td>
<td>0.57</td>
</tr>
<tr>
<td>9.6+</td>
<td>5.0</td>
<td>1.18</td>
<td>2.24</td>
</tr>
</tbody>
</table>

Table 2. Mean exposure in each trial of the KE risk display for the significant intervals above 8.6 RU.

Figure 5. Mean speed for the control condition and each display in each trial [Note: 1 mph = 1.6093 kph].
3.4. Subjective risk judgements
Owing to violation of parametric analysis assumptions, the subjective and evaluation data were analysed with non-parametric tests for the main design comparisons 1 and 2 (see figure 1).

3.4.1. Risk verbal ratings: The four verbal rating occasions of subjective risk were averaged within trial B.

(1) **Comparison 1**: Subjects in the risk display conditions reported that perceived risk was marginally higher (TH = 2.8; KE = 3.3) than did subjects in the control condition (Control = 2.3) \([KW(2) = 5.7, p < 0.01]\).

(2) **Comparison 2**: There was no comparable effect within conditions across trials.

3.4.2. Ad hoc ratings: Each of the five subjective *ad hoc* risk items administered in trial B were analysed separately. There were only significant effects reported for items measuring cautiousness and expected accident severity.

(1) **Comparison 1**: Subjects in the risk display conditions reported that they drove more cautiously (TH \(M = 59.4\); KE \(M = 57.0\)) than did the subjects in the control condition \((M = 52.8)\) \([KW(2) = 4.8, p < 0.10]\). Subjects using the KE display also reported greater perceived severity of accidents \((M = 8.16)\) than did the subjects in either the TH display condition \((M = 62.3)\) or the control condition \((M = 62.7)\) \([KW(2) = 6.6, p < 0.05]\).
(2) Comparison 2: For subjects with the KE display only, there was greater expected severity of accidents when using the display (trial B, $M = 81.6$) than without the display (trial A, $M = 74.1$, trial C, $M = 78.0$).

Figure 7. Coefficient of variation of speed for the control condition and each display in each trial.

Figure 8. Mean time headway for the control condition and each display in each trial.
Figure 9. Fifth percentile time headway for the control condition and each display in each trial.

Figure 10. Coefficient of variation of time headway for the control condition and each display in each trial.
3.5. **Task workload**
There was no significant effect of display type between conditions (Comparison 1) nor between trials within each condition (Comparison 2) on reported task workload.

4. **Discussion**
This study examined the impact of risk information on driving style in a simulated traffic environment comprised of a two-lane highway with traffic. Information about accident risk was provided in terms of the probability and severity of an accident by the use of scaled displays of time headway (TH) and kinetic energy (KE), respectively. It was hypothesized that the provision of risk information would result in a shift toward reduced exposure within high-risk categories, and increased exposure within low-risk categories. Risk display type was treated as a between-subject factor as well as within an A-B-A repeated measures design. The most reliable effect of the risk displays was evident from the within-subject comparison.

4.1. **Time headway**
Both risk displays produced consistent trend patterns indicative of a shift toward reduced risk exposure.

4.1.1. **KE display**: The KE display reduced exposure in the high risk (red) headway interval between 1.6 and 2.0 s. The KE display also appeared to marginally increase the amount of open-lane driving. As a result of a 6 s value assigned to open-lane driving, the KE display appeared to result in a larger average headway in comparison to the TH display and no display, as well as a marginal reduction in headway variation.

4.1.2. **TH display**: The most significant reduction in exposure with the TH display was in the ‘red’ headway interval between 1.1 and 1.5 s. This may reflect in part an artefact of the display coding scheme. It must be noted, however, that

![Figure 11](image-url)
the TH display did result in a significantly shorter 5th percentile headway than either the KE display or no display. The 5th percentile headway in trial B with the TH display was also significantly shorter than in the trials before (A) and after (C) the introduction of the display. This may reflect a number of possible factors. Drivers may have a tendency to underestimate time headway as they do with other time-based distance measures such as time-to-collision (McLeod and Ross 1983, Cavallo and Laurent 1988). The provision of time headway information may have shifted responses toward a shorter headway as perceived headway became more congruent with actual headway. Alternatively, either the nature of the TH display information or its dynamic display characteristics may have been compelling, thereby attracting prolonged attention. In this case, attention to this display may have delayed reactions to lead car events such that lapses into short headway were not anticipated (until appearing on the display). Similarly, lapses into short headway may have occurred during the shift of attention from the display to the forward scene (or vice versa). The KE display was more static and hence may not have been as distracting. Notably, there were no indications that either display resulted in greater reported workloads.

Carter et al. (1995) investigated the effects of continuous TH information on driver behaviour in actual on-road trials. In that study subjects drove an instrumented car on 4, 1-h open road sessions. Measures of TH and task loading were taken. TH information was displayed using a three-sectioned, variable length colour bar display (red = 0 to 1 s, amber = 1 to 2 s, green = 2 s and above). This was accompanied by an auditory tone when headway decreased below 1 s. Carter et al. (1995) found that this TH feedback display was effective in reducing the proportion of time spent at 1 s time headway or less, with no increase in task loading for the driving task. Note that this range of 1 s or less corresponded to the ‘red’ high-risk portion of the display. Thus, between these two studies, it appears that subjects are responsive to the saliency of the hazard colour-coding of the displays. In the current study, the sensitivity to colour-coding was evident even in the absence of an auditory alarm.

4.2. Speed choice (and kinetic energy)

4.2.1. KE display: The KE display produced the most consistent pattern of trends across scale intervals indicative of a shift toward reduced risk exposure in terms of accident severity defined by kinetic energy. This shift appeared at the interval boundary near 5.5 RU. This boundary was just beyond the visible range of the display scale (0 RU to 5 RU). This boundary also corresponded to a speed of approximately 70 mph [113 kph], which was the posted speed limit for the simulated highway. The presence of the KE display may have prompted subjects to adhere to the speed limit because of the heightened saliency of the effect of speed on accident risk. Alternatively, the display may have coincidentally drawn subjects toward a scale value equivalence of the speed limit in the attempt to keep the display active in the visible range of the scale. The most significant reduction in exposure attributable to the KE display was for the high-risk intervals (8.6 to 10 RU), which subsumed the maximum speed of the vehicle (95 mph, 153 kph). Moreover, the KE display resulted in significantly slower mean and 95th percentile speeds than either the TH display or no display. The mean and 95th percentile speeds in trial B with the KE display were also significantly slower than in the trials before (A) and after (C) the introduction of the display.
4.2.2. *TH display:* In contrast, the TH display promoted significantly greater exposure within these same high-risk intervals. Whereas the TH display did reduce exposure in the lower risk range between 6.6 and 7.0 RU, there was also some indication that the TH display may have increased higher risk exposure in the 8.1–8.5 RU interval. This increase in speed exposure may be attributable to attempts by subjects to overtake vehicles and remain in the open right (fast) lane more often to avoid activation of the TH display. A similar effect was reported by Jansen and Nilsson (1991) in their simulated evaluation of a collision avoidance system based on headway and relative speed. The KE display may also have prompted open-lane driving, but it also provides specific information that acts to reduce speeds.

4.3. *The relative effectiveness of risk displays*

Overall, the KE display was more effective in modifying driving style. It affected speed choice as well as time headway. Notably, the influence on time headway was contrary to the general observation that slower speeds result in shorter headways (for example, see table 2 of Colbourn *et al.* 1978). The KE display resulted in a lowering of speed with an increase in headway. The converse relationship of headway information affecting speed choice was not apparent. Indeed, the TH display may have encouraged excessive speeding.

These results suggest that subjects were more sensitive to information about accident risk in terms of the severity rather than the probability of an accident. Moreover, whereas both the accident risk displays resulted in greater awareness of risk, the KE display resulted in a greater perceived severity of accidents than did the TH display when interacting with traffic. Specifically, subjects with the KE display reported greater perceived severity of accidents than did the control or TH subjects. Neither display resulted in an increase in task workload, suggesting that the information provided did not incur an additional processing load or demand upon the subjects.

The limited influence of the TH display to promote safer driving behaviour suggests foreknowledge of accident severity rather than accident probability is more effective to inform safer driving. TH information indicates no risk in open-lane driving, despite the fact that some risk is present whenever the car is moving on the roadway. So in this sense, a TH display may be unduly optimistic about risk. By contrast, the KE display always indicates some degree of risk (severity) when the car is in motion (i.e. speed > 0). However, as this risk assessment is independent of likelihood of an accident, a KE display may be unduly pessimistic. This suggests that the two types of risk information—time headway (safety margin) and kinetic energy (survivability)—be combined into a single risk display.

Future research is planned to study algorithms by which to combine these measures to convey a more holistic representation of risk. Such a display could present risk as some derivative of dividing the kinetic energy expressed in Risk Units by instantaneous time headway expressed in seconds (RU/TH). For time headways less than 1 s, this calculation realizes a rapid increase in risk exposure as shown in figure 11. Note that the original KE display (i.e. risk as severity, RU) is equivalent in this formulation to a presumed headway of 1 s. Also, it is necessary to assume a default time headway value to represent some degree of risk when driving without traffic.
Alternative formulations may be based on the relative speed between the subject and lead car rather than the absolute speed of the subject car alone. This value can still be base-lined against the standard 30 mph [48 kph] crash against a fixed object, which itself reflects a relative speed difference (relative to a stationary object with zero speed). The 30 mph fixed barrier crash baseline remains valid given that the majority of rear-end accidents are with stationary (fixed) lead vehicles at intersections (Knipling et al. 1993). In the absence of traffic, there are numerous fixed road-side objects that may be hit in the course of a single vehicle road departure type accident.

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