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Evaluating the effects of bilingual traffic signs on driver performance and safety

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Variable Message Signs (VMS) can provide immediate and relevant information to road users and bilingual VMS can provide great flexibility in countries where a significant proportion of the population speak an alternative language to the majority. The study reported here evaluates the effect of various bilingual VMS configurations on driver behaviour and safety. The aim of the study was to determine whether or not the visual distraction associated with bilingual VMS signs of different configurations (length, complexity) impacted on driving performance. A driving simulator was used to allow full control over the scenarios, road environment and sign configuration and both longitudinal and lateral driver performance was assessed. Drivers were able to read one and two-line monolingual signs and two-line bilingual signs without disruption to their driving behaviour. However, drivers significantly reduced their speed in order to read four-line monolingual and four-line bilingual signs, accompanied by an increase in headway to the vehicle in front. This implies that drivers are possibly reading the irrelevant text on the bilingual sign and various methods for reducing this effect are discussed.

Keywords: Variable Message Signs; Bilingual; Driver performance; Workload;

AMS Subject Classification:

1. Introduction

There are a number of bilingual countries (e.g. Wales, Belgium, Canada, New Zealand) where two languages are given equal status, and provision needs to be made for speakers of both languages. This provision applies to general signage including road signs and this has led to the need for research that evaluates drivers' ability to perceive and comprehend them. In effect, when drivers encounter bilingual signs, they perceive double the amount of text, half of which is superfluous to them. This paper presents a study that examines whether bilingual signing affects driver performance and safety, using the local UK example of Welsh bilingual signs. The Welsh language is the oldest living language of Great Britain and one of the oldest in Europe. The population of Wales amounts to 5% of the UK total and it has a National Assembly responsible for developing and implementing policies which reflect the needs of Welsh people. The study focussed on using Variable Message Signs, due to their imminent introduction on Welsh roads.

1.1. The design of road signs

Road signs provide drivers with appropriate warnings and information as well as identifying legal requirements or instructions. To fulfil this function efficiently and therefore safely, the signs must:

1) Be easily recognisable and locatable within a complex visual scene.
2) Clearly indicate the status of the message (legal, warning or information).
3) Convey the message efficiently thereby minimising visual distraction.
4) Be comprehensible so that drivers can recognise the action (or choice) to be taken.
5) Be located such that the driver has sufficient time to act on the message.

The perception and comprehension of a road sign (and indeed text in general) can be broken down into three stages (Anderson 1990). The first stage comprises the perceptual processes by which the text on the road sign is encoded. The second stage is termed parsing whereby the words in the message are transformed into a mental representation of the combined meaning of the words. The third stage is the utilisation stage, in which drivers actually use the mental representation of the sentence's meaning. If the message is an assertion, the drivers may simply store the meaning in memory; if it is an instruction, they may obey.

Many studies of visual information processing have involved determining what can be extracted from a brief visual presentation and the resulting memory for this information (e.g. Sperling 1960). Displays of letters are presented briefly to participants who are then asked to recall as many as possible. Usually they are able to recall between three and six items, although they report they saw more, but could not identify them, i.e. they faded away. These basic perceptual experiments demonstrate that visual information presented to drivers should be limited in length and be in a relatively uncluttered environment. If information is presented too quickly in succession, drivers will be unable to process the messages effectively.

Once the road sign has been perceived, it then requires recognition. It is generally agreed that recognising a message involves feature analysis (e.g. Kinney *et al.* 1966). Here, the overall pattern is decomposed into a set of 'mini' features, which are recognised and then used to identify the pattern. Thus the letter 'H' consists of two vertical and one horizontal line and a specification of how they should be combined. In terms of recognition of the individual letters on a VMS sign, this would imply that as long as the individual features are readily recognisable, drivers should be able to interpret the message. Where problems might occur is where there are limitations in the sign design that do not allow the display of the features naturally used in text processing.

A further important consideration in sign design is that of context. When context or general world-knowledge guides perception, processing is known as top-down processing, because high-level general knowledge determines the interpretation of the low-level perceptual units (Tulving *et al.* 1964). With context, less information needs to be extracted from the word itself in order to identify it. These results strongly suggest that signing should be as context-relevant as possible and use familiar phrases or symbols.

As drivers, we are faced with enormous amounts of information to process in such a way that the environment makes sense. The more frequently processes have been practised, the less attention they require. Highly practised processes, which require little or no attention are referred to as automatic, while those processes that require attention are known as controlled (Schneider *et al.* 1977). With reference to the driving task, and in particular the reading of road signs, a designer should aim to implement a message or pictogram that is already known to the driving population or is already used in another context. This limits the time needed to perceive and parse a text message.

Some attempts at producing design guidelines for signs have been made, based on the time taken for drivers to read traffic signs (Forbes *et al.* 1965, Johansson *et al.* 1970). Research indicates that reading times typically increase in a linear manner with the number of names on a sign (Hall *et al.* 1991). This has implications for the design of bilingual signs, as they inherently display more information than their monolingual counterparts.

1.2. The use of Variable Message Signs

VMS have gained more importance over recent years due to the improved flexibility of signs brought about by the use of electronics and the widespread availability of communications. They have been used to supply drivers with up-to-date information about road and weather conditions and can be interfaced to traffic monitoring systems. The majority of studies on VMS focus on rates of compliance, either by using surveys or via observational studies (see Bonsall *et al.* 1999 for an overview). Some behavioural work has also been carried out, for example Rämä *et al.* (2000) found that VMS warning signs reduced the mean speed on slippery roads by 1–2 km/h. Other research on VMS has concentrated on legibility criteria in terms of character luminance (Kerr *et al*. 1987, Padmos *et al*. 1987, Colomb *et al.* 1991, Upchurch *et al*. 1992, Ullman *et al.* 2001). Research has indicated that drivers require approximately 1s per word presented on a VMS in order to perceive and process the information (Dudek *et al.* 1986). A limit of eight words, for drivers travelling at motorway speeds, was deemed to be the maximum that can be handled within the limits of human information processing.

The most common use for VMS is to display speed limit restrictions: some studies have reported good compliance rates, especially when the reason for the restriction is also displayed (McCoy *et al.* 1995, Garber *et al.* 1995). This is the main advantage of VMS: messages can be made to appear personalised and up-to-date. Their inclusion in a highway authority's traffic management plan is therefore understandable.

1.3. Bilingual signing

There has been little work carried out which has attempted to evaluate if drivers are able to glean the appropriate information from bilingual signs, without there being a degradation in their driving performance. Attempts to discover the optimum method of displaying bilingual text have been limited in scope, usually due to financial and technological constraints. For example, Anttila et al. (2000) tested an alternating bilingual sign (swapping between Swedish and Finnish every 2 seconds) against one which displayed the messages simultaneously. By recording eye movements, they inferred the visual demand of the signs. However the study was limited to one level of sign complexity and did not assess any other (driving) performance measures.

Research on static bilingual signs has confirmed increased reading times - by up to 15% - compared to their monolingual counterparts (Rutley 1972, Lesage 1978, Anttila *et al.* 2000). This is despite the fact that drivers need only read half of the information presented in order to glean the appropriate message. An increase in reading time for a particular sign would logically be accompanied by a decrease in the amount of visual attention paid to the road. Whether this leads to an increase in accident risk depends on the context of the driving situation (e.g. cars ahead, relative speed, proximity of cars in the adjacent lane). When considering the visual distraction of in-car systems, guidelines exist as to 'how much' distraction is acceptable (e.g. ISO 1997, Zwahlen *et al.* 1988). However, there is no baseline against which we can evaluate the level of visual distraction posed by road signs. As a result, researchers and policy makers have simply sought to <u>minimise</u> the reading time.

As the English and Welsh languages use the same alphabet (although the combinations of letters are different), when a monolingual driver is presented with a bilingual sign, they search the sign in order to locate the appropriate information. This may mean that, in effect, a driver has to read, or at least perceive, the whole sign in order to determine the relevant text. In Japan, where most signs on major roads are bilingual (Japanese/English), this is less of a problem as the two character sets are very different. To minimise the overall reading time where the character sets are the same, two approaches could be adopted. Firstly, the sequence of the languages could be optimised such that drivers learn that, for example, the English text is always uppermost. Secondly, attempts to increase the differentiation between the two languages could be made by using different colours or fonts.

There are a number of fundamental questions to be addressed in order to evaluate and optimise bilingual sign configuration. First, how do drivers respond to bilingual signs and does this have implications for traffic safety? If so, can reading times for bilingual signs be reduced by using one of the methods described above? The study presented here aimed to answer these research questions using a driving simulator and a number of bilingual VMS, of varying complexities.

1.4. The current study

There are a number of methodological issues relating to the evaluation of sign readability. Luoma (1991) and Martens (2000) provide an overview of a number of techniques that could be used and their limitations. Such techniques include the recording of eye movements, the use of verbal reports, behavioural responses and sign recall. The review suggests that each of these methodologies has its drawbacks and that, if possible, more than one method should be used. For example, whilst eye movements can pinpoint the direction of gaze, they do not necessarily measure attention. Verbal reports could be used as a supplementary measure although under high workload conditions these may be dispensed with by the driver. Behavioural responses are considered to be the most useful measure of sign perception and comprehension; however these rely on using signs that are instructional in nature in order to provide measurable responses. Overall, a behavioural response is arguably the most ecologically valid measure for road safety evaluations and this provides the focus of this study.

The study was designed to evaluate if drivers were able to maintain their normal level of driving performance whilst encountering different types of mono and bilingual VMS. A driving simulator was used to ensure repeatability of scenarios and the collection of detailed driver behaviour. While driving a simulated section of rural motorway, participants were presented with a range of VMS signs and instructed to read aloud the text in their preferred language as soon as they were able. They were also asked to carry out any instructions indicated on the signs. The complexity of the signs was varied by increasing the amount of information available to the driver. This allowed the direct comparison of, for example, a four-line bilingual sign with a four-line monolingual one. The VMS were presented to drivers under varying workload conditions and their behaviour compared using measures of speed, lateral position and headway to a lead vehicle. In addition to measuring driver performance, it was thought useful to try and quantify the actual amount of time it would take a driver to process the VMS. This was achieved by including a number of signs that gave drivers an instruction. The time taken for them to respond to this instruction was taken as a measure of response time. Both monolingual and bilingual participants were recruited for the study, as little is known about how bilingual drivers use bilingual signs. For example, as they are able, do they read both languages - or can they 'limit' themselves to reading just one of them? Linguistics research suggests that bilinguals never fully disengage from the other language (Green 1998), thus creating cross-language competition (Kroll *et al.* 2001).

2. Method

2.1. Participants

Twenty-four participants took part in the experiment. The sample comprised of an equal number of monolinguals (English) and bilinguals (English and Welsh). Monolingual participants were recruited using an existing database, whilst bilingual drivers were recruited via local Welsh clubs and social gatherings. There were no difference found, however, between these two groups, and therefore this variable is not considered in the results section. The sample was balanced for gender, and had a mean age of 28 years (SD 5.25). Participants had held their driving licences for a mean of 10.2 years (SD= 8.3) and had an average annual mileage of 8200 miles (SD= 3040). They were paid for their participation. Participants were instructed to read aloud the text on the VMS in their preferred language as soon as they were able to read it. They were also asked to carry out any instructions indicated on the signs.

2.2. Experimental environment

The study was carried out in the Leeds Advanced Driving Simulator, allowing the controlled and repeatable testing of sign configurations. The simulator is based on a complete Rover 216GTi, with all of its driver controls and dashboard instrumentation still fully operational. A real-time, fully textured and anti-aliased, 3-D graphical scene of the virtual world is projected on a 2.5 m radius cylindrical screen in front of the driver. This scene is generated by a SGI Onyx2 Infinite Reality2 graphical workstation. A Roland digital sound sampler creates realistic sounds of engine and other noises via two speakers mounted close to each forward road wheel. The projection system consists of five forward channels, the front three at a resolution of 1280 x 1024 pixels. The images are edge-blended to provide a near seamless total image, and along with two peripheral channels (640 x 480 each), the total horizontal field of view is 230°. The vertical field of view is 39°. A rear view (60°) is back projected onto a screen behind the car to provide an image seen through the vehicle's rear view mirror. For this study, the frame rate was fixed to a constant 30Hz. Although the simulator is fixed-base, torque feedback at the steering wheel is provided via a motor fixed at the end of the steering column and a vacuum motor provides the brake pedal booster assistance. Data are collected at the frame rate.

A two-lane road of UK motorway design standard was used for the experimental road, with a speed limit of 112kph (70mph). The road was comprised of 500m straight sections separated by 'filler' pieces of road. The VMS display was triggered 50m into the straight section and located 250m later. The road was approximately 32 km in length, with a light volume of surrounding traffic. In the outside lane, occasional vehicles travelling at 130kph (80 mph) passed the driver. A snapshot of the scene is shown in figure 1.

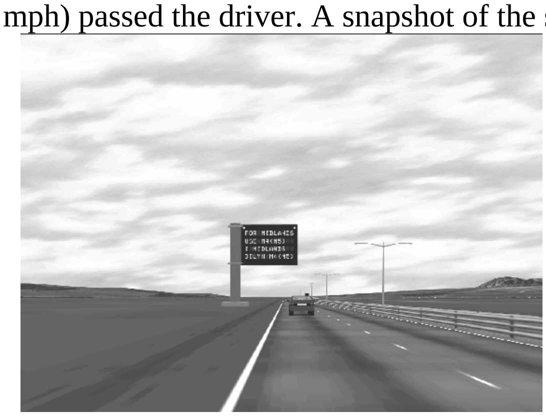

Figure 1. Four-line VMS sign within the simulated environment

Drivers were asked to follow a lead car until they reached the end of the route. They were asked not to overtake this car and to remain at all times in the left lane. Participants were required to drive the experimental road twice, with the order counterbalanced. The difference between the two roads lay in the behaviour of the lead car. On one of the roads the lead car remained at a constant speed (approximately 110kph). On the second road, the lead car varied its speed from 96-120kph on the road section where the signs were positioned, table 1.

Table 1. Speed profile of lead car in the high workload condition

Location from start of section (m)	0	100	200	300	400	500
Lead car speed (kph)	112	120	108	96	104	112

These two roads provided two workload conditions, with the second requiring more effort from the driver to maintain a safe headway to the vehicle in front. Participants underwent a familiarisation procedure before taking part in the main experiment. The simulator offers an ideal testing environment, as the readability of signs can be tested dynamically, i.e. whilst driving. This has obvious advantages over laboratory testing.

2.3. Sign configuration

Real-world VMS signs use capital letters only, with a case height equivalent to a 320 mm font (Highways Agency 1994). In order to ensure validity, the signs were designed such that they allowed the driver the same reading time as in the real world; this meant using a larger sign due to the reduced image clarity in the driving simulator. The characters were designed according to the Design Manual for Roads and Bridges (Highways Agency 1994) that specifies the pixels used in each character. The VMS signs were activated when the simulator passed a trigger point at the appropriate reading distance to ensure drivers were exposed to the sign for the same amount of time. Five VMS were presented to drivers as shown in figure 2.

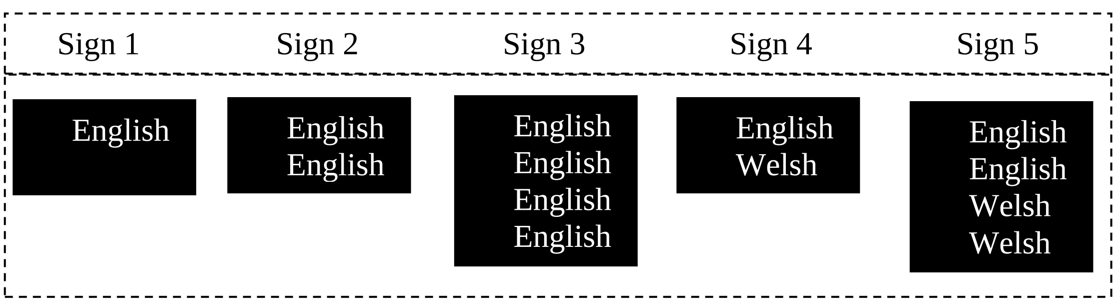

Figure 2. Sign types

The signs allowed the investigation of the effects of increasing lines and of increasing languages. For example, by comparing Signs 1,2 and 3, it was possible to discover if drivers performed differently as the number of relevant lines of text increased. Alternatively the comparison of Signs 1 and 4 and that of Signs 2 and 5, allowed the analysis of the effect of increasing the number of languages on the sign (whilst the number of relevant lines of text was held constant). The actual text used for these signs was in the form of information, for example 'FOR MIDLANDS, USE M4'.

A number of signs were also included which instructed the driver to use various vehicle controls. These four-line signs included three lines of road traffic related text with the fourth line being the instruction (e.g. flash your headlights). If the driver did not perform the action it was concluded that the fourth line could not be read in the available time.

A priori, it was hypothesised that four-line signs would be the most likely candidate to affect driver performance. Therefore a number of four-line signs were included to allow the testing of one of the most promising demarcation techniques - a separation line between the two languages (Jamson 2004). Driving performance when reading this sign was compared to that when reading the same sign, but without a separation line.

2.4. Data collection and analysis

Driver performance was measured using speed, lateral position and headway to a lead vehicle. The data were collected on the 500m straight sections of road and divided into ten sections of 50m each. This enabled the analysis of data as the driver approached the sign to discover, for example, which signs produced changes in driver behaviour, where these changes occurred and how long they lasted for. Driver performance on these sections was compared to that collected on a baseline section where no sign was present. The data were analysed separately for the two workload conditions, as the behaviour of the lead vehicle would directly affect the participant's behaviour. For example when the lead car slowed, the participant might also reduce their speed to maintain their desired headway – not as a direct result of them attempting to read the VMS.

As a measure of global subjective mental workload, the NASA TLX (Byers *et al*. 1989) was administered following each drive. This required drivers to rate their driving in terms of mental demand, physical demand, time pressure, performance, effort and frustration level. A bipolar scale represents each of these items; participants place a line on the scale between the two extremes of the item to indicate the strength of the attribute. This questionnaire was used to evaluate perceived differences in the two workload conditions.

3. Results

The main focus of this experiment was the detection of changes in speed and headway in the vicinity of the signs, and establishing which signs have the most impact. For each of the datasets (Low Workload and High Workload), analyses of variances were performed using Sign Type and Road Section as repeated measures. In the High Workload condition, only the minimum time-headway data was considered because, as explained above, the lead car's behaviour would directly affect absolute values of speed and headway. Driver Type (monolingual or bilingual) was also included as a between-subjects variable. However, no significant effects of this variable were found in any of the analyses.

First, paired t-tests on the separate components of the NASA TLX confirmed that participants perceived their mental workload to be higher when they were required to monitor the behaviour of the lead car whilst reading the VMS, figure 3. Workload scores for mental demand ($t(23)= -6.18$, $p<.001$), performance ($t(23)= -5.99$, $p<.001$) and effort ($t(23)= -4.83$, $p<.001$) were all higher in the High Workload condition.

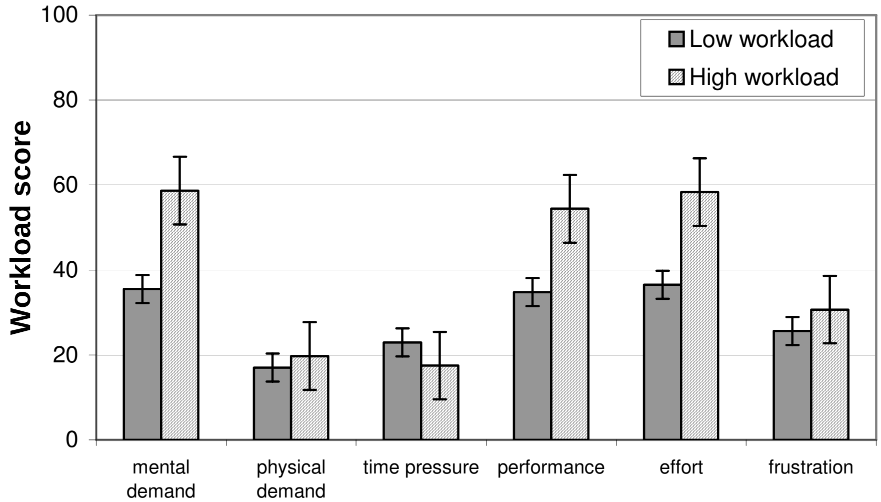

Figure 3. Mental workload scores (±SE)

3.1. Driver performance

Variables of speed, lateral position and headway were analysed using repeated measures ANOVA with two factors. The first factor, Road Section, corresponded to the ten road segments in the proximity of the VMS. The second factor, Sign type, had 6 levels corresponding to the 5 signs described in section 2.3 and a baseline road section (no sign present). Post-hoc contrasts were carried out where appropriate using the Bonferroni correction to minimise familywise error.

3.1.1 Speed. Mean speeds were calculated across each of the ten sections. In the Low Workload condition, there were main effects of Road Section with drivers reducing their speed in the vicinity of VMS signs, ($F_{9,207} = 32.38$, $p<.001$). Post-hoc pairwise comparisons showed that mean speeds in sections 3-7 (i.e. the period for which the driver was engaged in reading the signs) were lower than in all other sections, see figure 4. Mean speeds in the first and last sections were comparable; thus drivers increased their speed after having read the sign such that they returned to their observed speed before the sign was activated.

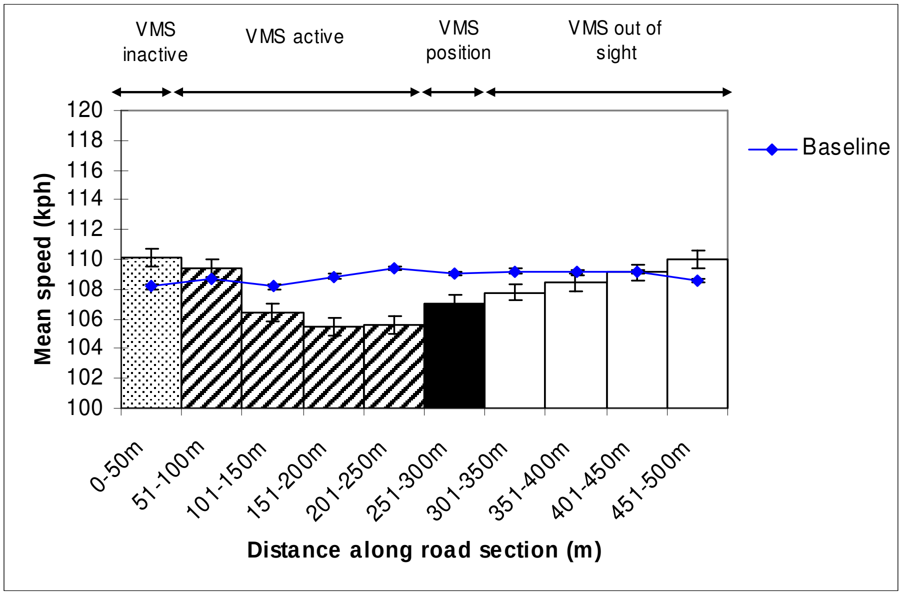

Figure 4. Mean speed (±SE) through the road sections (Low Workload)

In addition, there was a main effect of Sign type ($F_{5,115}$ = 162.52, p<.001) and an interaction between Sign Type and Road Section ($F_{45,1035}$ = 27.82, p<.001). With regards to the main effect, pairwise comparisons showed that mean speeds were lower for both the monolingual and bilingual four-line signs (in comparison to the baseline condition). Across all road sections, the average speed reduction was in the order of 3kph (2mph). Speed reductions for these four-line signs were similar. The Road Section*Sign Type interaction reveals more about the speed reductions in particular road sections for the different signs. As can be seen in figure 5, the one and two-line signs had no effect on drivers' speed. This was confirmed with repeated contrasts carried out separately for each sign type: on the whole there were no significant differences between the road sections.

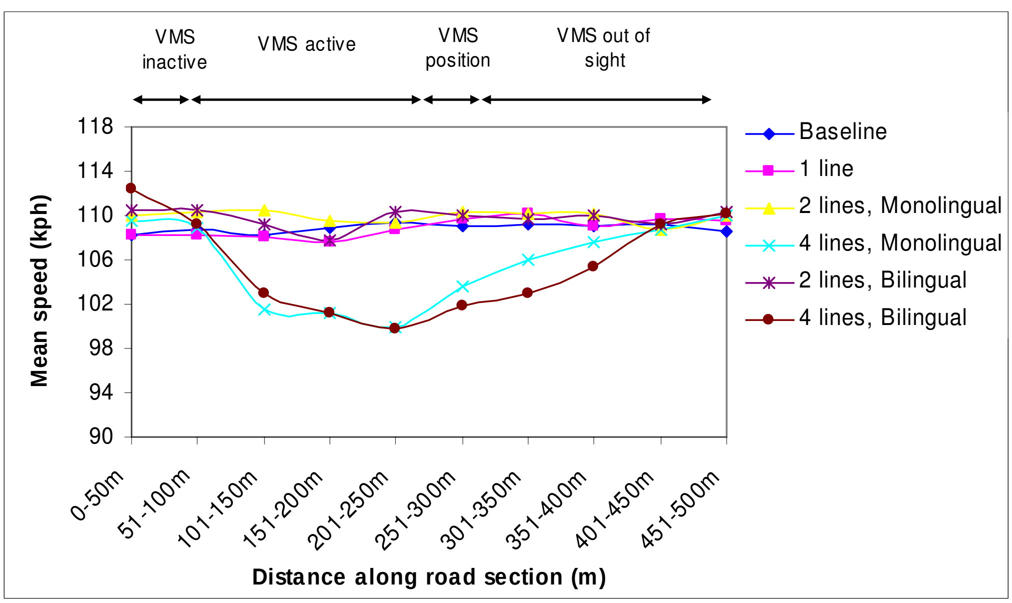

Figure 5. Mean speeds for different sign types (Low Workload)

For each of the four-line signs, changes in speed are apparent as drivers approach and pass the VMS. For each, a maximum reduction of approximately 11kph (7mph) was observed by the time drivers had reached the sign. This represents a deceleration rate of approximately 0.37ms^{-2} and is the result of engine braking, i.e. drivers simply released the accelerator (as opposed to using the foot brake). Slight differences were observed between these two signs in that when confronted with the bilingual sign, drivers reduced their speed earlier (p<.01) and then did not attain their baseline speed by the time they had reached the last road section (p<.001). Therefore, there seems to be evidence of a 'hang-over' effect, perhaps due to the fact that drivers were still trying to process the four-line bilingual sign.

The High Workload condition produced similar results in terms of mean speeds. However this measure is of less interest than that of headway, as this provides us with a measure of the safety margin that drivers are willing to adopt whilst reading the VMS.

3.1.2. Car following. A car following task was used to evaluate drivers' ability to adapt their driving behaviour whilst reading the VMS. It measures the ability of drivers to maintain a safe headway to a lead vehicle and has been used as a measure of driving safety in numerous studies of impairment (e.g. Brookhuis *et al.* 1987, Ramaekers *et al.* 1994). Only headways of less than 6 seconds were used as higher values assume that drivers are not intending to follow the lead vehicle (Vogel, 2002). Minimum time headways were calculated to reflect the smallest safety margin that drivers were willing to adopt. The minimum headways for the Low Workload condition are shown in figure 6. Main effects of both Sign Type ($F_{5,115}$ = 52.50, p<.001) and Road Section ($F_{9,207}$ = 5.21, p<.001) were found. Pairwise comparisons indicated that drivers adopted longer minimum headways when they encountered four-line signs compared to the baseline condition. This is simply an effect of the speed reductions found in the previous section - when drivers were reading the four-line signs, they reduced their speed. This would result in a longer headway to the vehicle in front.

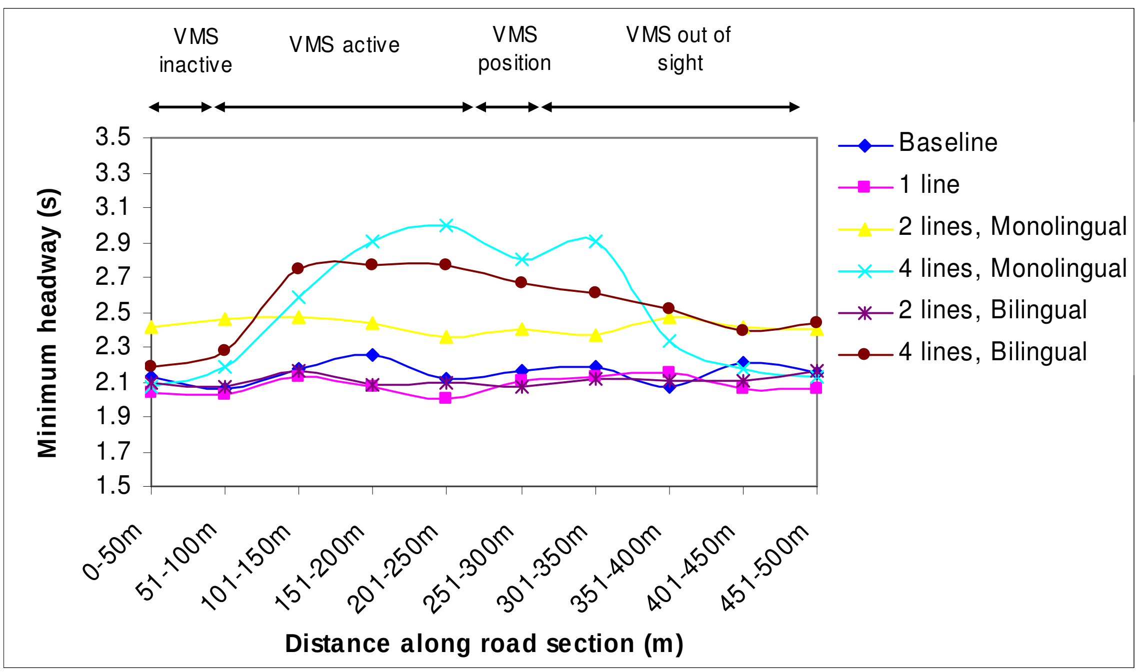

Figure 6. Minimum headways for the Low Workload condition

Of more interest is what happens when drivers are faced with a higher workload. Are they able to adapt their speed to that of the vehicle in front in order to maintain the same headway margin? A Sign Type*Road

Section interaction, ($F_{45,1035}$ = 5.54, p<.001) in the High Workload headway data suggests not, figure 7. It appears that drivers are sufficiently loaded with the additional task of reading the four-line signs such that they are willing to accept a smaller lead time to the vehicle in front. On average, their headway reduced by one second, whilst reading the signs.

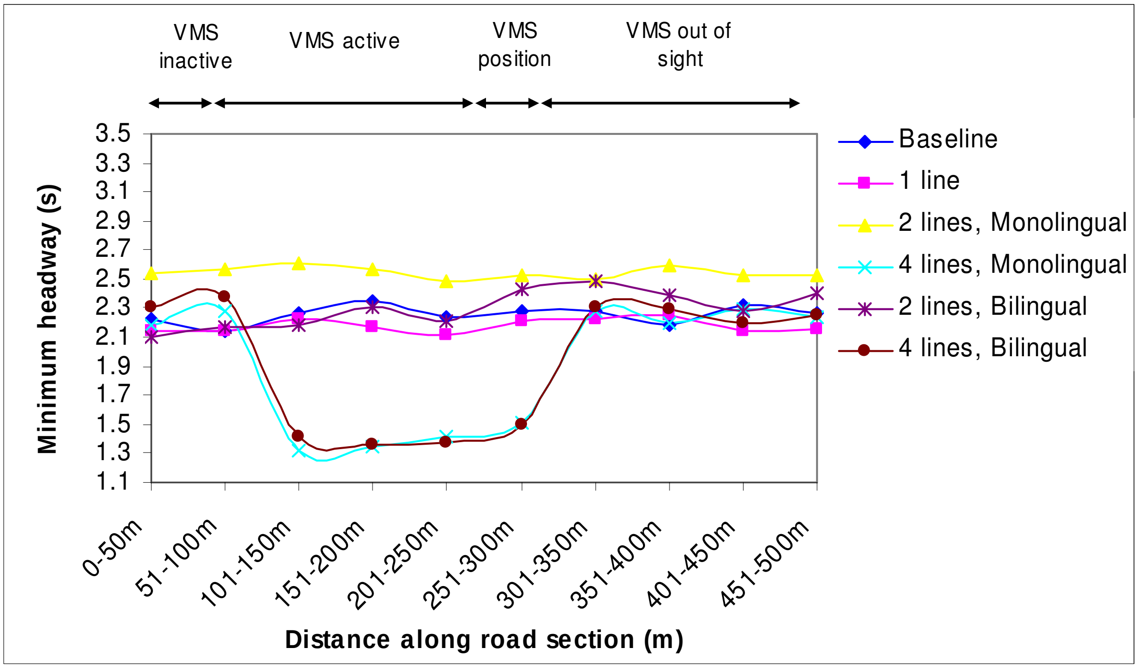

Figure 7. Minimum headways for the High Workload condition

3.1.3. Lateral deviations Standard deviation of lateral position (SDLP) was used as an indicator of drivers' ability to control their vehicle and prevent it wandering out of lane. There were no significant main or interaction effects of Sign Type or Road Section on SDLP. This is likely to be an effect of the reductions in speed noted above, such that drivers were able to control their steering whilst reading the signs because they compensated by reducing their speed.

3.1.4. Response accuracy The data presented above suggest that drivers have difficulty in reading the four-line signs without adapting their driving behaviour. Whether or not they are able to actually comprehend all four lines of the sign was tested by the inclusion of a number of one, two and four-line signs that required them to perform an action. The one-line signs simply displayed the instruction e.g. 'Flash your headlights'. The two-line signs contained one line of information, followed by the instruction. The four-line signs contained three lines of instructional text, with the last line being an instruction. Drivers' ability to perform the instruction was used as a measure of whether or not drivers had enough time to read all four lines. Response time was also recorded. Different types of instructions were provided to minimise learning effects.

Ninety-nine % of drivers succeeded in carrying out the instruction when faced with the one and two-line signs. This fell to 86% for four-line signs. Thus even when drivers compensated by lowering their speed, they still performed worse when encountering these longer signs. The second element of this assessment concerned the time drivers took to respond to the instruction on the sign. A significant effect for the number of lines of relevant text was found ($F_{[2,392]}$=168.84, p<0.001), table 2.

Table 2. Response times		
No. of lines of relevant text	Mean RT (s)	Std. Error (s)
1	2.81	0.26
2	3.27	0.11
4	6.43	0.24

An incremental increase in response time was observed as the number of lines of relevant text increased. Post-hoc testing showed that there was a reliable difference between two and four-line signs only. In other words, whilst there was a relatively small increase in response time when the number of lines doubled from one to two (16%), response times doubled when lines increased from two to four lines.

3.1.5 Demarcation A separation line was introduced on some signs to investigate whether this type of demarcation technique could improve the readability of the four-line bilingual signs. No significant differences were found across any of the variables when such a sign was compared to an identical one without a separation line.

4. Conclusions

Participants in this study were required to read and react to a number of monolingual and bilingual signs under both high and low workload driving conditions. Subjective mental workload scores suggested that drivers were able to differentiate between these two conditions, in that they reported that their performance deteriorated and they felt they had to increase their effort and as a consequence experienced higher mental demand. Whilst both monolingual and bilingual drivers were recruited for this study, no differencess were found between the two groups.

Drivers' ability to maintain their baseline driving performance whilst reading a selection of VMS was investigated. This driving performance consisted of both longitudinal and lateral measurements and was monitored on their approach to and passing of the signs. It was of interest to see if and how drivers adapted their behaviour and also whether there was a period of 'recovery', after having passed the sign. The most interesting analyses were that of the interaction between Sign Type and Road Section. This provided a temporal analysis of behaviour making it possible to pinpoint where any changes in behaviour occurred, depending on the type of sign drivers encountered.

Drivers were able to read one and two-line monolingual signs and two-line bilingual signs without disruption to their driving behaviour. However, both four-line monolingual and four-line bilingual signs impacted on driver performance, when compared to the baseline condition. Drivers reduced their speed by approximately 11 kph (7 mph), over a distance of 250m, in order to read these types of signs, achieved by engine braking. The fact that this speed reduction was the same for each of the four-line signs, suggests that drivers are perhaps reading, or at least searching, the irrelevant text on the bilingual sign. In addition, whilst drivers were able to recover from the monolingual sign (i.e. they returned to their previous speed), drivers were still travelling slowly after they had passed a four-line bilingual sign. This suggests that the drivers were perhaps still trying to process the information and work out whether they had missed something vital. This type of effect has been observed in a number of studies, whereby increases in cognitive load have led to speed reductions, e.g. whilst using a mobile phone (Burns *et al.* 2002, Haigney *et al.* 2000, Reed *et al.* 1999) or a navigation system (Srinivasan *et al.* 1997). Researchers have interpreted this in different ways; some believe it is a compensatory process that drivers engage in to reduce their accident risk, whilst others purport that drivers are simply paying less attention to the task of speed regulation.

With regards to response times, these increased with the number of lines of relevant text. Drivers were able to read and respond to signs that were one or two lines in length within a relatively similar timescale. However, when drivers were required to read four lines of text, their response time was significantly higher. This suggests that drivers had to 'chunk' the information, using several glances to the sign, in order to complete the task - although this could only be confirmed using additional data collection techniques (eye-movement recording). This chunking technique is a reasonable one to adopt, as long as the sign is within the driver's sight distance for long enough. For example, based on the response time of 6.43s, driver would require a four-line sign to be in legible view for approximately 200m (at motorway speed).

5. Practical implications

The results of this experiment suggest that in the High Workload condition, where drivers were required to adapt their headway to the vehicle in front, observed minimum headways decreased. Drivers appeared either to accept a shorter safety margin or not notice that the vehicle in front was decelerating. Either situation could impact on both the drivers' ability to avoid a collision and the severity of one should it occur.

The practical implications of this speed reduction and reduction in following headway are decreased traffic flow stability and an associated increase in accident risk. Drivers reading long (four-line) messages reduce their speed. Following drivers are reading the same message and while also beginning to reduce speed might not respond appropriately to the slowing of the lead vehicle. As inter-vehicle headways decrease, the margins available for drivers to take avoidance action are reduced and accident risk increases. Avoidance actions, when required, become more severe and 'shockwaves' develop in the traffic flow. The shockwave phenomenon is most often observed on motorways, where decreases in speed occur not only at the site of the problem (or sign) but also further back in the traffic stream where the reason for the speed reduction would not be visible to drivers. Such speed variation has been linked to increased accident risk (Garber *et al.* 1989, Aljanahi *et al.* 1999). These studies suggest that reducing speed variance and 85th percentile speed (the speed exceeded by the fastest 15% of drivers) are the most important aspects of speed to target for improved road safety.

This study has attempted to benchmark the possible effects that bilingual VMS might have on driver performance by comparing them with monolingual signs of varying lengths. The results suggest that drivers encountering four-line bilingual signs attempt to read the whole sign and that this process takes in the order of 6s. This is probably split into smaller chunks of time, separated by glances back to the road ahead. Highway engineers should take this into account when locating four-line VMS so that drivers have adequate sight distance.

With drivers reacting to such signs by slowing down, it is sensible to try and limit the visual distraction by the use of separation techniques. One such technique was tested in this study (a separation line) but it was not found helpful to the drivers. This could be a novelty effect in that drivers need to learn such techniques in order for them to be useful. Thus, multiple presentations may have been needed in order to draw out these advantages and further studies should concentrate on developing effective demarcation techniques.

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