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Cognitive compatibility of motorcyclists and car drivers

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ABSTRACT

Incompatibility between different types of road user is a problem that previous research has shown to be resistant to a range of interventions. Cars and motorcycles are particularly prone to this. Insight is provided in this paper by a naturalistic method using concurrent verbal protocols and an automatic, highly reliable semantic network creation tool. The method shows how the same road situation is interpreted differently by car drivers and motorcyclists in ways congruent with wider accident rates. Analysis of the structure and content of the semantic networks reveals a greater degree of cognitive compatibility on faster roads such as motorways, but evidence of more critical incompatibilities on country roads and junctions. Both of these road types are implicated in helping to activate cognitive schema which in turn generate stereotypical behaviors unfavourable to the anticipation of motorcyclists by car drivers. The results are discussed in terms of practical measures such as road signs which warn of events behind as well as in front, cross-mode training and the concept of route driveability.

1. Introduction

It makes intuitive sense that motorcyclists will interpret the same road situation differently to car drivers. The question this paper explores is whether this can really be regarded as the case, and if so, whether car drivers and motorcyclists can be regarded as cognitively compatible? If they are compatible then safety interventions concerned with the objective state of the situation (i.e. increased rider conspicuity) will be more likely to have an effect. This is because drivers will be interpreting the situation in a way that is already favourable to the anticipation of other road users. If they are incompatible then a more nuanced approach might be needed. For example, no matter how visible a rider may be, if the driver is operating in a situation which is generating a strong stereotypical response which is unfavourable to the observation of other road users, then in order to improve safety the mental representation of the situation becomes as important as its objective state.

1.1. The difference between motorcycles and cars

Driving a car is different to riding a motorcycle. Motorcycles have hand controls for throttle, front brake and clutch (all of which are foot operated in cars) and foot controls for gear selection (which are hand operated in cars). Motorcycles are smaller, lighter, occupy less road space, are more manoeuvrable, faster, require balance, and in most cases afford an elevated view of the road compared to cars. Unlike car drivers, motorcyclists are directly exposed to the environment in which the machine is operating and to the noise, vibration and other sensations that result from its interaction with the road and the manipulation of its controls. Car manufacturers ordinarily go to great lengths to ensure that drivers are isolated from many of these same sensations, indeed, drive-by-wire throttles, power steering and in-car entertainment means that this isolation can be profound (Walker et al., 2001, 2006, 2007). Motorcycles, on the other hand, afford the rider with a direct and unassisted mechanical link between the primary control inceptors (i.e. throttle, steering, brake and gears) and the control effectors (throttle butterflies, headstock and forks, brake calipers, gearbox selector forks). This, combined with elevated power to weight ratios, confers a high degree of directness and responsiveness to the controls that is not replicated in most modern production cars. All these factors combine to highlight the seemingly obvious point that driving a car is not the same as riding a motorcycle, and that each road user will likely adopt different mental strategies to suit their vehicular contexts. These differences become manifest in the types of road accident that motorcyclists have compared to car drivers, with a particular type of accident hinting at a more fundamental incompatibility. This is the case of car drivers being the cause of so-called 'right of way' accidents (e.g. pulling out in front of a motorcyclist from an adjoining road).

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A generic example of cognitive incompatibility might be described by Norman (1990) as a 'gulf of evaluation'. This describes a person's attempts to make sense of their context and how it matches their expectations and intentions. In Norman's examples, designers and users of a system bring to bear different cognitive models of a system based on their own understanding of it, leading to incompatibilities between what the designer expects and what the user wants. Replace 'designers and users' with 'motorcyclists and car drivers' and it is apparent that similar 'gulfs of execution' can exist in terms of how identical road situations are interpreted, and what those situations might 'afford' for different road users. The concept of 'affordances' reflects the Gibsonian (1977, 1979) idea that a relationship exists between people and their immediate context and the Neisserian (1976) concept that the environment is sampled, which in turn modifies behavior, which in turn guides further exploration. Affordances infer that the perceived state of a given context is as important as its objective state. Exploration infers the role of more fundamental processes in safe driving behavior such as visual search patterns. Research continues to show that visual search patterns differ between road users of different characteristics driving over identical roads (e.g. Underwood et al., 2003; Hosking et al., 2010).

Incompatibilities between different groups of road users are cited as one of five key road safety problems that are persistent over time, between nations, and not easily solved (Elvik, 2010). Problems at the motorcycle-other road user interface are well rehearsed in the literature with Clarke et al. (2007) revealing specific problems with how other road users perceive motorcyclists. This problem is rendered all the more interesting because drivers who are more likely to have difficulty interpreting a road situation involving an oncoming motorcyclist tend to be older, more experienced drivers who would ordinarily be expected to interpret a situation correctly. Another interesting finding is that whilst car-drivers and motorcyclists seem to have the most problems interacting with each other at junctions, motorcyclists seem to encounter more problems with the road itself, such as geometric features like curves and bends (Clarke et al., 2007; Daniels et al., 2010). Perhaps the clearest evidence of cognitive compatibility issues between car drivers and motorcyclists is provided by Magazzù et al. (2006) who found that car drivers who also held motorcycle licenses were less likely to be responsible for motorcycle-car crashes than drivers with car-only licenses. What previous studies seem to show, therefore, is that identical roads can be experienced differently by different road users, and that this interface can be mutually reinforcing or conflicting. From an experimental perspective, motorcyclists offer an independent variable of sufficient strength to be able to observe such effects directly in a naturalistic setting. Given increasing ridership (aided by congestion charging, environmental concerns and other societal factors which favour motorcycle usage), and the disproportionate number of motorcycle accidents (e.g. Clark et al., 2004), such opportunities also enable a much needed insight into accident prevention.

1.2. Mental representations

The notion of cognitive compatibility infers a "mapping of the relevant information in the situation onto a mental representation of that information" (Rousseau et al., 2004, p. 5). The term 'mental representation' reflects two aspects. Firstly, a mental representation infers that information elements are structured. A mental representation is not merely about the presence or absence of discrete elements but also about their interconnection. Secondly, it reflects the "hypothetical nature of perceptual experience" (Bryant et al., 2004, p.110). A mental representation is a model (e.g. Banbury et al., 2004), "a representation that mirrors, duplicates, imitates or in some way illustrates a pattern of relationships observed in data or in nature [. . .]", or "a characterisation of a process [. . .]". A mental representation needs to provide the rider or driver with "explanations for all attendant facts" (Reber, 1995; p. 465, 793) which in turn does not necessarily require a particularly rich or detailed model of the situation, indeed, it would be a highly inefficient representation if it did. On the contrary, there is good evidence that the better the representation, the more parsimonious it is (e.g. Gobet, 1998; Chase and Simon, 1973). The more parsimonious, the more that raw informational elements are combined into higher levels of abstraction or themes. The interplay between the quantity of information contained in a given mental representation and its configuration gives rise to a number of interesting structural characteristics. An example is described by Metcalf's Law (e.g. Metcalf, 1973). This states that the configuration of any given quantity of information embodies a property called value (e.g. information elements increase in value the more they are linked to other information elements). According to Metcalf's Law, as the number of links between individual elements increases linearly, the value of the entire configuration of elements and interconnections, or the rider's/driver's mental representation, increases exponentially. So when discussing cognitive compatibility both structure and content are important.

1.3. Cognitive compatibility

Gaining insight into mental representations, in naturalistic environments or otherwise, is experimentally and conceptually challenging. That said, the representation of knowledge in a network is not a new concept and semantic networks have been used by cognitive psychologists as a way of representing the association between items within a concept since the 1970s. Semantic networks are based on the long held belief that all knowledge is in the form of associations and represent concepts by depicting linked nodes in a network (Eysenck and Keane, 1990). Within a semantic network each node represents an object. Nodes are linked with edges typically specified by verbs or by analyzing the closeness of concepts using some form of Thesaurus learning algorithm. A variation on this theme is 'concept maps' (Crandall et al., 2006). Concept maps are based on Ausubel's theory of learning (Ausubel, 1963) which suggests that meaningful learning occurs via the assimilation of new concepts into existing concepts within the mind of the learner. With close similarities in both approaches, Anderson (1983) proposed 'propositional networks' to describe activation in memory. Salmon et al. (2009) and Stanton et al. (2009) have since extended this approach into the realm of situational awareness and have anchored it successfully to a generative model of cognition (e.g. Neisser's perceptual cycle, 1976) and to schema theory (Bartlett, 1932). Schema theory describes how individuals possess mental templates of past experiences which are mapped with information in the world to produce appropriate behavior. A schema is rather like a mental template, which is neither completely new behavior nor merely a repetition of old behavior, but is behavior which is generated from a familiar set of initial conditions, both mental and physical. Schema theory offers an explanation for the paradoxical case described above in which more experienced drivers seem to have greater degrees of cognitive incompatibility with motorcyclists. In this case, because cars are more numerous than motorcycles (in the UK at least), repeated experience with the latter contributes towards mental templates which generate strong stereotypical behaviors potentially unfavourable to the latter.

The concept of genotype and phenotype schemata are particularly relevant here. Genotype schemata can be thought of as the 'Global Prototypical Routines' contained in the mind of the person, the propensity to behave in a certain way in a situation containing certain features. Phenotype schemata refer to local state specific routines, or activated schema brought to bear on a specific problem in a specific situation. Hollnagel (1998) uses a similar distinction to illustrate how generic error modes (the genotype) may be related to observed errors (the phenotype) in the world. Based on this analysis it could be stated that the root of cognitive incompatibility between different road users are faults in triggering appropriate schema. Norman (1981) puts forward three basic genotype related problems which account for the majority of errors. These are activation of wrong schemata (due to similar trigger conditions as encountered in routine driving situations), failure to activate appropriate schemata (due to a failure to detect trigger conditions indicating a change in the situation, such as a motorcycle approaching rather than a car) and a faulty triggering of active schemata (triggering the schemata either too early or too late to be useful, such as stopping the car in the path of the oncoming motorcyclist).

The use of networks and their associated theoretical concepts are therefore well established in the field of psychology and the human sciences more generally. As the summary of previous research shows, good progress has been made already by using human factors methodologies as a way of populating such networks and drawing inferences from them. A novel development reported in this paper is the use of a sophisticated software tool called Leximancer™ which automates the creation of such networks, and does so with complete repeatability. Leximancer™ uses text representations of natural language in order to create themes, concepts and links. This is achieved by algorithms which refer to an in-built thesaurus on the one hand, and to features of text such as word proximity, quantity and salience on the other. Leximancer™ has been used extensively in previous studies. It has provided insight into organizational change (Rooney et al., 2010), intergroup communication (Hewett et al., 2009), analysis of web content (Coombs, 2010) and large scale meta-analyses of themes within scientific journals (Cretchley et al., 2010). The application of this technique to a more intensive form of analysis based on concurrent verbal protocols of real-life transport contexts is a novel one.

1.4. Exploratory analysis

The discussion above establishes a relationship between semantic networks, knowledge representation and schema theory. This means that properly constructed semantic networks can serve as a useful analogue for aspects of a road user's mental representation of a situation. It is from this theoretical basis that we can proceed into the generation of more practical accident analysis and prevention insights. The first of these is to analyse the question of whether vehicle type (car versus motorcycle) does actually affect an individual's experience of the same (or very similar) road situation. To do this, semantic networks can be created based on concurrent verbal transcripts performed at the time the situation is experienced. Cognitive compatibility can be assessed by analyzing the structure and content of those networks over different situations. Under the rubric of distributed situational awareness (e.g. Salmon et al., 2009; Stanton et al., 2009) it is perfectly feasible for there to exist pronounced differences in content and structure, but for those differences to be compatible and mutually reinforcing. That said, it is equally feasible that differences in content and structure will be incompatible, with the behavioral effects of one mental representation not compensated for by the other. The present study proceeds in an exploratory manner, trading strict experimental control for ecological validity. The use of concurrent verbal protocols and semantic networks is positioned in such a way as to complement rather than replace more controlled experimental approaches. The method is intended to generate more insight than exists currently, to suggest new avenues of practical safety intervention, and to link psychological theory to accident analysis in a novel, systematic and repeatable way.

2. Method

2.1. Participants

Twelve participants took part in the study using their own vehicles. They were comprised of six car drivers and six motorcyclists. All participants held a valid UK driving licence with no major endorsements, and reported that they drove approximately average mileages per year for their vehicle type. The participants fell within the age range of 20–35 years old. Mean driving experience was 5.83 years for the car drivers and 5.33 years for the motorcyclists. In the case of motorcyclists, this age range spans the group (16–29-year olds) who make the longest and most frequent motorcycle trips (Chorlton and Jamson, 2003), and in both cases, participants have been exposed to many hundreds of hours of driving or riding experience. An all male sample was used for two reasons. Firstly, within the context of this focused, intensive study, gender differences could provide an unwanted confounding variable. Secondly, motorcycles comprise only 3% of registered vehicles on British roads thus reducing their total availability for participation, added to which, males are 7 times more likely to make a motorcycle trip (Chorlton and Jamson, 2003).

2.2. Design

The experiment is exploratory and based upon a naturalistic on-road driving paradigm where individuals use their own vehicles around a defined course on public roads. The experimenter travelled in the front passenger seat during the observed runs in the cars, or followed on another motorcycle during the observed runs with the motorcyclists. This controlled for the possible effects of observation upon driving behavior. Drivers/riders were required to provide a concurrent verbal protocol as they traversed the road course, which was then analysed using a text analysis tool called Leximancer (see Smith, 2003). This enabled differences in textual and thematic content to be systematically analysed, and the structure of the verbal protocol to be mapped using semantic networks. These output are dependant upon two independent variables: vehicle type and road type. Vehicle type has two levels: car or motorcycle. Road type has six levels: motorway (freeway), major road, country road, urban road, junction and residential road. Controlling measures were self-report questionnaires of driving style, recordings of average speed and time, and demographic data. All experimental trials took place at defined times to control for traffic density and weather conditions.

2.3. Materials

Six cars (a Volkswagen Golf TDi, Audi TT, Toyota Tercel, BMW 325i, Volkswagen Golf CL and Peugeot 309 GLD) and six motorcycles (a Triumph Daytona 900, Suzuki TL1000R, BMW R1100GS, Laverda 750 Formula S, Suzuki GSX400F and Honda CBX750) were used in the study. Car drivers were audio recorded whilst they drove using a microphone and laptop computer. Motorcyclists were audio recorded using a microphone mounted in the chin-piece of their crash helmet and a digital recording device carried on their person. An identical set up was used for the accompanying rider.

Driving style was assessed with the DSQ driving style questionnaire (West et al., 1992). This is a 30-item questionnaire from which six driving style dimensions are extracted: speed, calmness, planning, focus, social resistance and deviance. The DSQ was selected on the basis of it having wide application, being relatively quick and non-invasive for participant's to complete, and possessing a good degree of cross-over between motorcycle riders and car drivers. That said, the question items referring to the 'deviance' scale were removed due to an incompatibility. For example, certain question

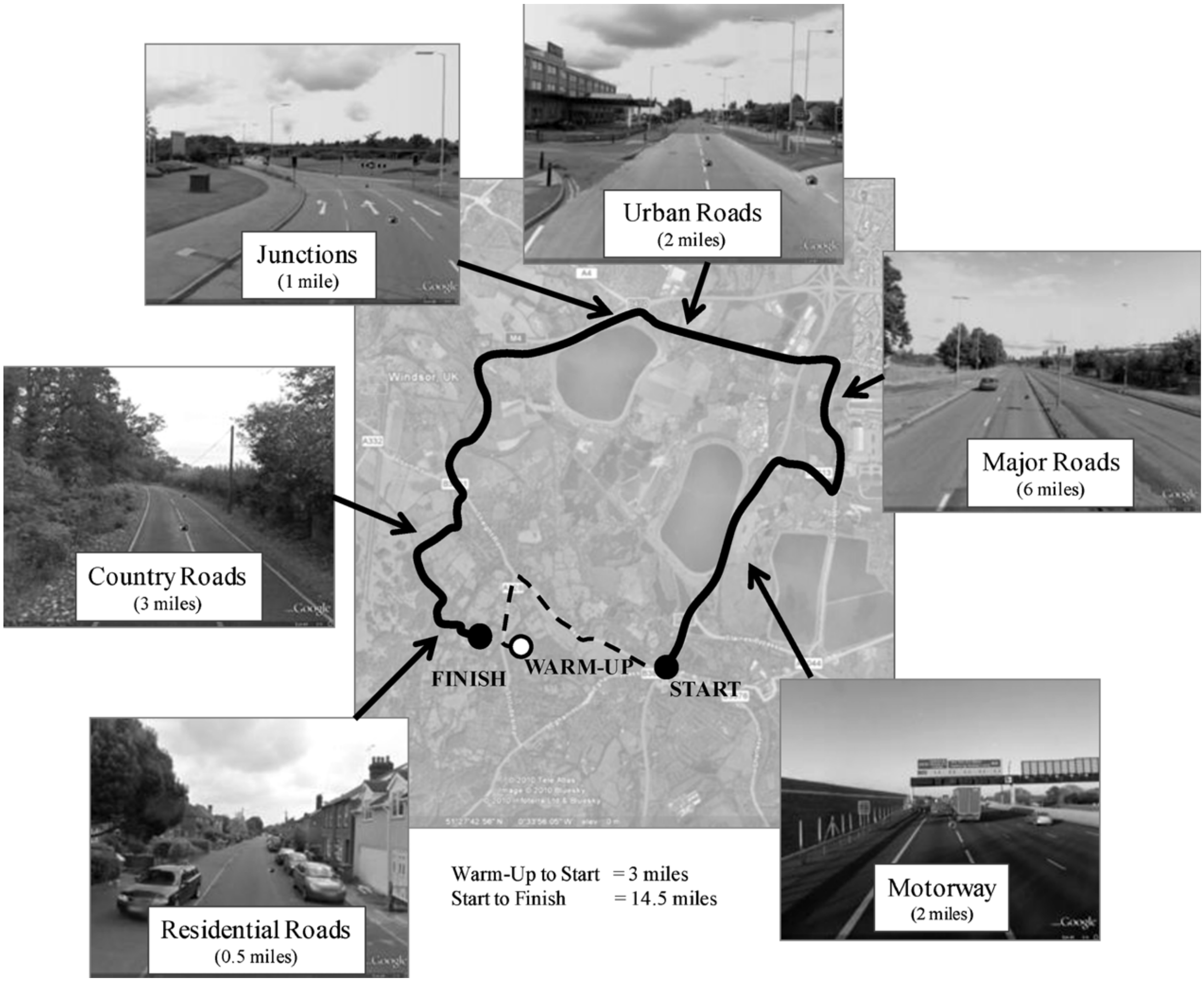

Fig. 1. Diagram of the 14.5-mile on-road course.

items referred to behaviors that are legitimate for motorcyclists but not car drivers such as filtering through traffic and certain forms of overtaking.

The on-road route is contained within the West London area of Surrey and Berkshire and was 14.5 miles in length not including an initial three-mile stretch used to warm up participants. The route is comprised of one motorway section (70 mph speed limit for 2 miles), seven stretches of major road (50/60 mph speed limits for 6 miles), two stretches of country road (60 mph speed limit for 3 miles), three stretches of urban roads (40 mph limit for 2 miles), one residential section (30 mph limit for 0.5 miles), and fifteen junctions (>30 mph speeds for 1 mile). Experimental runs took place at 10:30 in the morning and 2:30 in the afternoon (Monday–Thursday) and 10:30 on Friday. These times avoided peak traffic hours for the area, and all runs were completed in dry weather. Fig. 1 presents a diagram of the route and road types.

2.4. Procedure

Formal ethical consent was obtained from all participants before the study commenced with particular emphasis on control of the vehicle and safety of other road users remaining the participants' responsibility at all times. Participants then completed the Driving Style Questionnaire followed by a comprehensive experimental briefing. An instruction sheet on how to perform a concurrent verbal protocol was read by the participant, and the experimenter provided examples of the desired form and content. In the case of the motorcyclists, they were further instructed that the experimenter would follow them on another motorcycle in an offset road position. They were instructed to use their mirrors as normal and watch for directional indications from the experimenter and to act upon them.

There then followed a warm-up phase. A three-mile approach to the start of the test route enabled the participants to be practised and advised on how to perform a suitable concurrent verbal protocol. This involved providing suggestions and guidance from the passenger seat, or in the case of motorcyclists, pulling over to review the audio transcript and advise where necessary. All participants were able to readily engage in this activity and minimal advice was needed. The rate of verbalizations, combined with the relatively un-demanding and benign traffic situation present on the route (hence the time of day chosen for the drives), seem to indicate that providing a verbal protocol did not interfere with the participant's primary task of vehicle control nor did it seem to impact to any noticeable degree on workload.

During the data collection phase the experimenter remained silent aside from offering route guidance and monitoring the audio capture process. For the motorcyclists the experimenter followed at a safe distance, remaining in the lead rider's rear view mirrors by riding in an offset position, and using their own indicators to guide the participant around the route. Small signs were placed at the roadside to serve as boundaries between road types. These signs were captured on video during observed runs with car drivers, which in turn enabled the verbal transcript to be suitably partitioned. In the case of motorcyclists, the observer carried an audio capture device synchronized with that carried by the participant. When the participant was observed to pass a roadside marker the observer noted this verbally. The two transcripts were combined to allow the data to be partitioned as before.

The verbal protocol data was then treated with Leximancer™, a software product that automates the process of semantic network creation. Six main stages are performed in order to transform verbal transcripts into semantic networks:

1. Conversion of raw text data (definition of sentence and paragraph boundaries, etc.).
2. Automatic concept identification (keyword extraction based on proximity, frequency and other grammatical parameters).
3. Thesaurus learning (the extent to which collections of concepts 'travel together' through the text is quantified and clusters formed).
4. Concept location (blocks of text are tagged with the names of concepts which they may contain).
5. Mapping (a visual representation of the semantic network is produced showing how concepts link to each other).
6. Network analysis (this stage is not a part of the Leximancer™ package but was carried out as an additional step to define the structural properties of the semantic networks).

3. Results and discussion

3.1. Analysis of control measures

This section seeks to establish the presence (or otherwise) of major confounding variables which may influence subsequent analyses of differences between car drivers and motorcyclists. The variables selected include speed, time to complete the on-road course and the results of a driving style questionnaire. If marked differences on these parameters do not exist then it is safe, within the context of a naturalistic study, to proceed with the comparison. Table 1 presents the descriptive, inferential and effect size correlation analysis of the median speed around the experimental road course, and the outcome of the DSQ.

Statistical power is not sufficiently high in either case of median speed and DSQ score to assume that there is literally zero difference between the two types of vehicle. The effect size correlation R_{bis} suggests that approximately 2% of the variance in DSQ scores is explained by vehicle type, and therefore a function of the type of people who choose to use these vehicles. On the other hand approximately 21% of the variance in median speed is explained by vehicle type, and the difference between the two groups is statistically significant at the 9% level ($U(N1 = 6, N2 = 6)$ 7.5, $p < 0.09$). Motorcyclists are therefore completing the course more quickly, however, reference to the size of this effect reveals that this difference is of an order of magnitude of 5 mph or less. In summary, analysis of the control measures strongly suggests that the potentially confounding effects of average speed/time and innate driving style have been controlled to a tolerable degree.

3.2. Concurrent verbal protocol: semantic extraction

A metric for the amount of semantic content able to be extracted from different road scenarios is given by the word count of the verbal transcripts. The total word count across all road types and both road users is 28,169. Under the null hypothesis the total word counts for motorcyclists and car drivers should be 14,084 (i.e. 28,169/2). In fact the findings show the total word count for motorcyclists (16,678) to be 18% higher than that for car drivers (11,491). This occurs despite motorcyclists spending on average approximately 3 minutes less time travelling around the course. The largest difference in word count occurs in motorway driving and junctions, with motorcyclists providing 23% and 20.7% more verbal content respectively than car drivers. Controlling for the effect of each road section's mileage to produce a normalised 'words per mile' metric reveals a distinct pattern. Overall, the fastest roads, with speed limits of 70 mph (i.e. motorways), 60 mph (i.e. major and country roads) and 40 mph (i.e. urban roads) produce less than 150 words per mile. Junctions and residential roads (with 30 mph limits) produce in excess of 350. The first point to make is a methodological one. Clearly there is sufficient spare mental capacity, particularly for motorcyclists, for a rich verbal commentary to be provided across all road types. Indeed, the more challenging road types yield more content rather than less, which is what interference due to workload might otherwise suggest. The second point is a theoretical one. It is evident that motorcyclists are able to extract more semantic content from the same situations than car drivers. Furthermore, it would seem that the quantity of semantic content is contingent on the speed and hazard incident rate of different road types. Hazard incident rate is a concept used in police driver training. A hazard is defined by Coyne (2000) as anything potentially dangerous and/or has the potential to cause the driver to change the position and/or speed of their vehicle. Clearly, some road types such as motorways, with restricted access, grade separated junctions, lower speed differentials and gentle alignments have a lower hazard incident rate than a busy urban road, with unrestricted access, at-grade crossings and potentially unfavourable geometry. In other words, 30 mph in an urban setting typically provides many more hazards per mile than 70 mph on a motorway. Differences in word count, therefore, seem to reflect the presence of more stimuli. Whether more stimuli might lead to deeper and/or different reasoning entirely is the topic of the next sections.

3.3. Semantic networks: analysis of structure

A total of 12 semantic networks are produced from the semantic content captured in the verbal transcripts, six for each of the two road user types (motorcyclist and car driver). These six networks refer in turn to the six road types encountered around the test route (motorway, major, country, urban, residential roads and junctions).

Analysis of these networks now proceeds on the basis of their structure. The structural analysis employs techniques from graph theory to view the semantic networks in terms of nodes (n) and edges (e). These procedures help to reveal important underlying

Table 1
Summary of analysis for control measures.

	Mean bike	Mean car
Lap speed	34.83 mph	30.99 mph
Mean overall DSQ score	3.93	3.46

	Test statistic (U)	Probability	Effect size (R_{bis})	R^2 (variance explained)
Lap speed	7.50	$P < 0.09$	0.46	0.21 (21%)
Mean DSQ score	9.00	$P = 0.47$	0.13	0.02 (2%)

structural properties of the semantic networks which are not readily apparent from visual inspection alone. The metrics used are: density, diameter and centrality.

Density is given by the formula:

$$\text{Network density} = \frac{2e}{n(n-1)}$$

where e represents the number of edges or links in the semantic network and n is the number of nodes or semantic concepts. The value of network density ranges from 0 (no concepts connected to any other concepts) to 1 (every concept connected to every other concept; Kakimoto et al., 2006). Density is a metric which refers to the semantic network as a whole and is a measure of its overall level of interconnectivity. Higher levels of interconnectivity suggest a richer set of semantic links and a well integrated set of concepts. A more dense network is also likely to have more well connected concepts and shorter average path lengths. In order to diagnose the latter, a further metric is employed: diameter.

Diameter is given by the formula:

$$\text{Diameter} = \max_{uy} d(n_i, n_j)$$

where $d(n_i, n_j)$ is "the largest number of [concepts] which must be traversed in order to travel from one [concept] to another when paths which backtrack, detour, or loop are excluded from consideration" (Weisstein, 2008; Harary, 1994). Diameter, like density, is another metric which refers to the network as whole. Generally speaking, the bigger the diameter the more concepts within the semantic network that exist on a particular route through it. Again, generally speaking, a more dense network will have smaller diameter (because the routes across the network are shorter and more direct) whilst a less dense network will have a larger diameter (as routes across the network have to traverse a number of intervening semantic concepts). This measure is related to the idea of clustering and to individual semantic concepts which are more or less well connected than other concepts. In order to diagnose this facet a further metric is deployed: centrality.

Centrality is given by the formula:

$$\text{Centrality} = \frac{\sum_{i=1,j=1}^{g} \delta ij}{\sum_{j=1}^{g} (\delta ij + \delta ji)}$$

where g is the number of concepts in the semantic network (its size) and δji is the number of edges (e) on the shortest path between concepts i and j (or geodesic distance; Houghton et al., 2006). Centrality gives an indication of the prominence that each concept has within the semantic network. Concepts with high centrality have, on average, a short distance (measured in edges) to other concepts, are likely to be well clustered and to be near the centre of the network. Concepts with low centrality are likely to be on the periphery of the network and to be semantically distant from other concepts.

Fig. 2 presents the results of applying density, diameter and centrality to the 12 semantic networks created from the verbal protocol data. The radar plots show that the structural metrics have some contingency upon road and road user type.

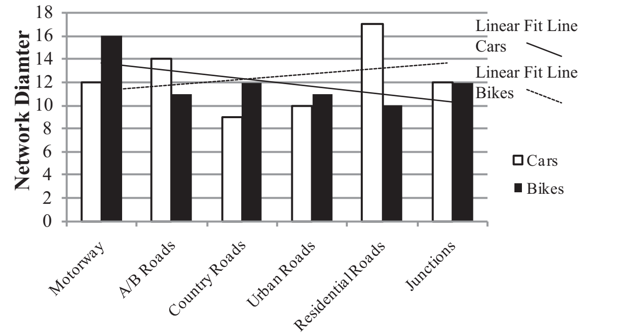

Fig. 3. Results of diameter versus road type. Linear fit lines show that as road speeds and hazard incident rates increase, the diameter of the semantic networks increases for car drivers and decreases for motorcyclists.

The mean level of interconnectedness of the semantic networks (as measured using the density metric) is 0.07 for car drivers and 0.08 for motorcyclists. This difference is very small as demonstrated by the almost identical level of density across most road types. However, it can be observed that the semantic networks for motorcyclists becomes more densely interconnected when travelling over residential roads (0.12 compared to 0.08).

The results for diameter show that whilst the overall level of interconnectedness is broadly similar across road user types, the detail of that interconnectedness does differ. Fig. 3 reveals an interesting pattern. A linear trend line seems to suggest that as road speeds, and hazard incident rates increase, the diameter of the semantic networks for motorcyclists decreases. This means that the extent of direct access to semantic concepts increases with hazard incident rate. The reverse trend seems true for car drivers.

Analysis of the metric centrality shows that, overall, as road speeds decrease so too does the mean level of clustering. In other words, as speeds increase specific semantic concepts become much more relevant than others. An exception to this overall pattern is when travelling over country roads, where the average level of clustering increases markedly for car drivers. A less dramatic increase can also be observed for both road users in respect to junctions where the mean level of clustering increases once more.

In summary, the overall level of semantic interconnectivity is broadly comparable between motorcyclists and car drivers. The main finding is that whilst word counts increase with hazard incident rate, the prominence of individual concepts tends to decrease (for both road users). This seems to reflect the presence of a broader range of hazards (e.g. parked cars, hidden turnings, pedestrians, etc.) for slower urban and residential roads compared to motorways and major roads (where none of the above hazards apply and attention is focused on a much reduced, but nonetheless important subset). Another key structural difference between motorcyclists

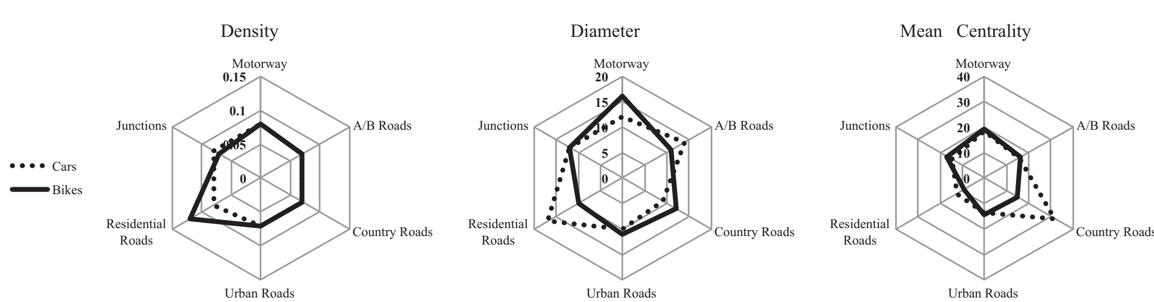

Fig. 2. Radar plots of network density, diameter and centrality and their contingency upon road and road user type.

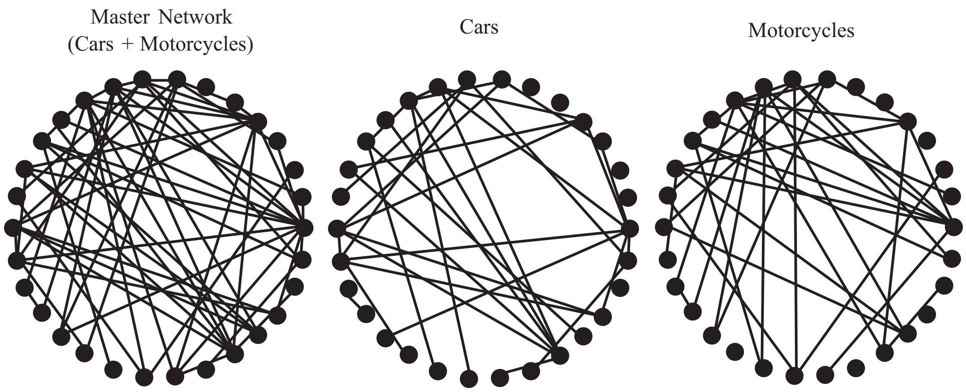

Fig. 4. Master network created from shared concepts with links between concepts derived from individual semantic networks.

and car drivers seems to be in respect to diameter, whereby average path lengths between semantic concepts decrease with hazard incident rate for motorcyclists (suggesting a more integrated mental representation), and increase for car drivers (suggesting a less integrated mental representation).

3.4. Semantic networks: phenotype and genotype schemata

An important observation is that despite quite high levels of overall structural similarity between semantic networks, there is a high level of dissimilarity in content. Less than half (mean = 43.3%) of individual semantic concepts for motorcyclists are shared with car drivers. The fact that a high degree of similarity exists in the structure of the networks despite less than half of the concepts being shared prompts two further levels of analysis: a structural examination and a more detailed analysis of shared content.

The structural analysis proceeds by taking the mean of 43.3% shared semantic concepts and translating them into the 30 individual concepts which are common across all road types and road users. From these a master semantic network is created. The 30 shared concepts represent the nodes for this network (n) whilst the interconnections between them (the edges e) are based on those contained in the individual networks. For example, concept A might be linked to concept B in two individual networks (e.g. the networks for motorways and major roads). This in turn creates an edge value of 2 in the master network. The master network, therefore, represents the totality of shared concepts extracted from the verbal protocol data and the totality of links within the separate networks which join them. Fig. 4 shows this master network of shared semantic concepts in relation to the differing pattern of activation when the data is partitioned into car drivers and motorcyclists.

Under the null hypothesis, it would be expected that the interconnections between shared semantic concepts for car drivers and motorcyclists would be the same. This is not the case. From Fig. 4 it is visually apparent that the structure differs, moreover, that the number of edges is slightly greater in the motorcycle network ($e = 36$) compared to the car network ($e = 33$). As a result, there is a small difference in overall interconnection (i.e. density) of 0.076 for car drivers and 0.083 for motorcyclists. Slightly more pronounced are the overall differences in network diameter. Here it can be noted that the semantic network of shared concepts for motorcyclists (5) is smaller than the same network for car drivers (7). As before, this indicates that motorcyclists have slightly more direct access (without intervening concepts on the pathways across the network) within the core set of concepts common to both types of road user. The most pronounced results refer to centrality. When the motorcycle and car networks are compared on this measure it can be observed that 63% of shared concepts increase their centrality/clustering in the motorcycle network compared to the car network. 6.7% of concepts remain unchanged (the null hypothesis) while 30% of the shared concepts decrease in the car network compared to the motorcycle network. In summary, more than double the number of shared concepts are more clustered, and therefore more closely linked semantically in the motorcycle network compared to the car network. These findings communicate that whilst 30 individual semantic concepts are identical between car drivers and motorcyclists, their interconnection differs markedly. Structure is thus independent of content.

Table 2 provides a further interpretation of the findings. The mean difference in centrality between motorcyclists and car drivers is 0.69 (SD = 6.35). This means that 19 of these shared objects differ between road user types by less than 1 standard deviation either side of the mean difference value. These semantic concepts therefore remain relatively enduring regardless of road user and can thus be related to the concept of genotype schemata, or Global Prototypical Routines. In other words, individual semantic concepts within 1 standard deviation of the mean can be associated with strong stereotyped responses to generic situations. The 5 semantic concepts which increase their centrality beyond one standard deviation of the mean for motorcyclists, and the 4 semantic concepts which do the same for car drivers, can be associated with phenotype schemata. Because their importance changes meaningfully depending on road user type, they can be understood as relating to Local State Specific schema brought to bear on a specific situation. Table 2 shows the mapping between semantic concepts and genotype/phenotype schemata.

In summary, genotype schemata seem to relate to manoeuvring 'round' obstacles, over'take'ing, selection of 'gears', awareness of speed 'limits' and control of 'speed', understanding the 'traffic' situation and 'road' layouts, such as 'roundabouts', 'lanes', traffic 'lights' and 'corners'. They also relate to events that are 'coming' or that are happening 'ahead' or those which are occurring 'behind' and observable in 'mirrors'. They also seem to refer to actions that are happening currently (such as 'pulling away' and 'pulling off') and actions which are 'going' to happen in the future.

Phenotype schemata, or local state specific routines associated with motorcyclists, include a lot of 'noticing', 'checking', 'doing' and 'moving' whereas for car drivers they involve 'looking', other 'cars', events specifically happening in 'front' and awareness of a particularly steep 'hill' (which does not affect the motorcyclists to any great degree due to higher power to weight ratios). The main differences between motorcyclists and car drivers, at this simple level of analysis, seem to be in situational awareness. Motorcyclists seem to demonstrate greater emphasis on activities concerned with its attainment (e.g. noticing and checking) whereas car drivers seem to refer to particular sources of information (e.g. other cars and

Table 2
Concepts whose difference value is within 1 SD of the mean relate to genotype schemata. Concepts whose difference value is outside 1 SD of the mean relate to phenotype schemata.

Concept	Example	Difference (% relevance)	SD
Noticing	"noticing a yellow temporary sign for diverted traffic"	12.22	
Checking	"checking all round as we move away"	11.28	
Moving	"bit of traffic turning in front of us so we're not moving"	10.94	Phenotype schemata
Doing	"we're doing well under 40 that's for sure"	9.4	
Check	"need to turn right, check both mirrors and indicate"	8.24	
Round	"looking at the big truck, [he's] not signaling, not going to argue with him, he is coming round"	4.46	
Gear	". . .just kick it up a gear again, about 3000 rpm"	3.35	
Speed	"picking up the speed just very gently"	3.29	
Limit	"ok, we're entering a 30 [speed] limit"	2.99	
Traffic	"joining the M25 now. . .lots of traffic braking and switching lanes"	2.7	
Roundabout	"gently roll off, I can let everything pass me, on the roundabout, and over we go"	2.5	
Lane	"I'll just pull over into this left hand lane"	2.43	
Slow	"just let the car slow itself down as I indicate"	1.99	
Car	"oh, just changed into 2nd at bit too higher revs there so the car jolted"	1.2	Genotype schemata; mean = 0.7 ± 1 × SD (6.35)
Lights	". . .and the lights are red"	0.72	
Take	"unfamiliar junction here so I'll take it easy"	0.45	
Coming	"nobody coming the opposite way"	0.44	
Ahead	"traffic building up ahead"	0.28	
Mirrors	"just going to check the mirrors to make sure it's ok to pull out. . ."	0.14	
Bend	"Going to slow down for this bend"	0	
Braking	"easing off, braking a bit more. . ."	0	
Corner	"that's fine, this corner is slightly blind. . ."	−1.12	
Behind	"check the car behind"	−2.04	
Going	"just going to pull in and let them through"	−2.14	
Road	". . .and road conditions look very dirty actually, lot of mud, there's obviously some road works going on?"	−3.98	
Pulling	"no cars coming, pulling forward. . ."	−4.04	
Hill	"use plenty of revs to it up this hill"	−9.1	
Look	"some kids by the parked cars to look out for"	−9.95	Phenotype schemata
Cars	"potential for cars pulling out in front of me"	−12.64	
Front	"clear on the road in front"	−13.09	

events in front). This form of analysis is developed further in the next section.

3.5. Semantic networks: thematic analysis

In Leximancer^{TM} concept groupings are referred to as 'themes'. These help to raise the level of analysis from the individual items of sometimes rather idiosyncratic keywords to that of broader, highly connected clusters related to how a situation is interpreted. Themes are ascribed a relevance value by Leximancer^{TM}. This is derived from the number of times the theme occurs as a proportion of the most frequently occurring concept (Smith, 2003).

There are a total of 64 individual themes extracted from the 12 semantic networks. Not all of these themes score highly in terms of relevance so the data is filtered in order to capture those scoring in excess of 70% within either (or both) the motorcyclist and/or car driver data sets. The filtering process reduces the number of themes from 64 to a high scoring subset of 20. Table 3 presents a summary of the results obtained. Under the null hypothesis it would once more be expected that the matrix of populated cells in Table 3, and the relevance values they contain, would be the same for motorcyclists and car drivers (a difference value of zero). Once more, this is not the case.

Visual inspection of Table 3 reveals differences between road users. Out of the 120 cells contained in the matrix, 49 are not equal to zero. Of those 49, 21 show differences in relevance of 70% or more. Of those 21, 11 have increased relevance for motorcyclists and 10 for car drivers. In summary, then, there is 59.2% thematic overlap between motorcyclists and car drivers but 41.8% of strong thematic difference. This overall difference continues into road types. For motorcyclists, the pattern of results is consistent with the earlier findings on network diameter. Generally speaking, as road speed decreases and the hazard incident rate increases, the number of themes, and their relevance, tends to drop. This finding appears to triangulate with the findings presented on centrality.

Motorway: Car drivers interpreted this situation in relation to events behind and in front of them. They also interpreted it in terms of the road itself, in particular the configuration of lanes and shoulders (and their position on it and the relative position of others). Motorcyclists interpret this situation quite differently. Much more relevant is what is 'ahead', what is 'coming' towards them, and what is in 'front' (including the slip road they plan to take in order to leave the motorway). Motorcycles are much more manoeuvrable (so are not as constrained to lanes as car drivers) and more responsive longitudinally (even at high speeds they can accelerate very rapidly). As such, events behind tend to be receding rather than encroaching, compared to events in front, which are approaching and need to be dealt with. Based on this reading of the semantic network, and despite thematic differences, there would nonetheless seem to be evidence of cognitive compatibility between car drivers and motorcyclists: the former engage with this situation with schema relevant to events behind them, whilst motorcyclists bring to bear schema relevant to what is in front. Providing issues concerned with conspicuity, perception of closing speeds, blind spots, etc. can be resolved then the fundamental mental theories brought to bear on the motorway situation are broadly compatible.

Major road: With freedom of movement becoming more constrained due to increasing traffic movements, fewer lanes and narrower road widths, the semantic networks for motorcyclists now become more similar to the semantic networks for car drivers on motorways. The situation is now interpreted more in terms of what is 'behind', the 'road' conditions (in terms of braking and manoeuvring) and 'lanes'. Car drivers, meanwhile, continue to interpret this situation in terms of what is behind, but now also

Table 3
Matrix of themes and road types. Cells populated with the difference in % relevance between motorcyclists (positive numbers), car drivers (negative numbers) and instances of thematic overlap (zero values/null hypothesis).

	Motorway	Major road	Country road	Urban road	Residential road	Junction
Ahead	96	−30	12	0	0	0
Behind	−16	−69	0	−14	−48	0
Car	0	0	74	0	54	0
Cars	0	0	0	0	−77	0
Coming	13	46	−14	100	−100	10
Corner	0	0	−94	0	0	0
Front	−48	84	24	0	0	−12
Gear	0	0	0	78	12	0
Going	27	0	−83	0	−60	7
Lane	−43	54	0	0	0	−84
Moving	78	0	0	0	0	0
Pull	0	0	0	−100	0	−12
Road	−67	100	100	−23	0	−80
Shoulder	−36	0	0	0	0	0
Signal	0	0	0	0	0	70
Slow	0	0	−71	0	0	0
Third	0	0	−86	−4	0	−56
Traffic	31	0	0	0	0	100
Van	0	0	0	0	0	−80
Slip	100	0	0	0	0	0
Number of themes increasing in relevance for motorcyclists	6 (sum 480%)	4 (sum 284%)	4 (sum 210%)	2 (sum 178%)	1 (sum 54%)	4 (sum 187%)
Number of themes increasing in relevance for car drivers	5 (sum 210%)	2 (sum 99%)	5 (sum 348%)	4 (sum 141%)	4 (sum 285%)	4 (sum 324%)
Number of themes remaining the same for both road users	9 (45% overlap)	14 (70% overlap)	11 (55% overlap)	14 (70% overlap)	10 (50% overlap)	14 (70% overlap)

understand it in terms of traffic that is 'coming' from other directions. Again, cognitive compatibility is in evidence with both road users interpreting the situation in terms of 'lanes', with motorcyclists now bringing to bear schema related to encroachments from behind whilst car drivers deploy schema related to events 'ahead'.

Country road: The semantic networks for car drivers now reflects a situational interpretation that has switched from 'behind' to 'ahead'. The challenge in these situations is less to do with traffic conflicts, lanes and road layout and more to do negotiating natural features and corners. Planning ahead also rises to prominence. Motorcyclists also interpret this situation in terms of what is ahead but, surprisingly, give less direct emphasis to hazards such as corners. That said, much more indirect emphasis is made in relation to the state of the road itself (in terms of adhesion, conditions, etc.). Unlike motorways and country roads, areas of cognitive incompatibility are revealed in both road users now bringing to bear schema related to 'ahead'. For car drivers 'ahead' occurs in conjunction with schema concerning planned action. Whilst the theme of 'car' becomes very prominent for motorcyclists, perhaps reflecting awareness of typical 'planned actions' performed by car drivers in these situations, the two mental theories of the situation have become uncoupled. In this situation, only one road user type is attempting to anticipate the actions of the other. Whilst the motorcyclists operate with anticipatory schema incorporating awareness of the car in front, and of planned actions resulting thereof, the car driver's schema driven response in these situations is to focus on what is ahead.

Urban road: Both motorcyclists and car drivers interpret this situation in terms of events 'behind' but once more much greater emphasis is placed by motorcyclists on what is 'ahead'. Selection of the appropriate 'gear' is also important for both road users. The prominence of the concept 'slow' for car drivers reflects the fact that progress is much more frequently impeded compared to motorcyclists, who are able to use their awareness of what is 'ahead' in order to maintain progress. Evidence of cognitive incompatibility is once again indicated, with anticipatory schema of traffic that is 'coming' only in evidence for one road user (motorcyclists). Car drivers seem to be operating in the realm of schemas concerning events behind and how this interacts with correct road positioning and lane selection, in conjunction with schema to do with pulling away in response to stimuli such as traffic lights and appropriate gaps in traffic.

Residential road: In this situation, both road users refer to individual vehicles around them, but they are of much more prominence to car drivers (whose progress is once again more significantly impeded). Lower speeds also raise to prominence the concept of being in the correct 'gear' for motorcyclists. In this situation, there is little to suggest significant cognitive incompatibility. Motorcyclists seem to be relatively unaffected by the impediments that seem to drive much of the active schema for car drivers. Instead, their schema seem more related to the behavior of cars around them, and in proper control of their machine (in terms of appropriate gears, etc.).

Junctions: Interestingly, given that a major source of traffic conflicts between cars and motorcycles occurs at junctions, this situation is interpreted very differently between the two road users. Car drivers are once again concerned with the appropriate travel 'lane', 'pulling' away and specific vehicles (e.g. 'van'). The semantic networks for motorcyclists reflect a need to give information to other road users in the form of 'signals' and a wider appreciation of 'traffic' (rather than specific vehicles). In this situation there are areas of cognitive compatibility, with motorcyclists clearly bringing to bear schema that attempt to compensate for car drivers, who are more preoccupied with road position and lane manoeuvres. Cognitive incompatibility is in evidence because car drivers seem to be operating with schema concerning events 'coming' or in 'front', with no corresponding relevance given to events 'behind'. As a result, the effect of signals and other measures motorcyclists take to increase awareness may be limited.

4. Conclusion

The paper has shown how a reliable, automated, semantic network creation process, coupled to concurrent verbal protocol data, is able to provide some initial insights into how different road users experience the same road situations. In turn, this provides insight into the key transport safety challenge of compatibility between different road users. From this analysis it is clear that motorcyclists interpret the same road situations differently to car drivers. In many road circumstances this interpretation appears to have important areas of mutual reinforcement, with strong stereotypical responses which favour the anticipation of each other. This is not the case for all road types. Not surprisingly, the two road types of most concern to motorcyclists (junctions and country roads) are interpreted differently and in ways that are more difficult to reconcile for both road users. The study thus shows a good degree of triangulation with acknowledged sites of car/motorcycle incompatibility, for example, at junctions (i.e. 'right of way' accidents) and on country roads (i.e. single vehicle accidents on bends). The exploratory analysis described in this study is compatible with a number of more practical accident analysis and prevention measures, all of which present themselves as candidates for further in depth study.

The use of verbal protocols, task talk-throughs, interviews and focus groups is well established in the human factors literature as a way of defining information and training needs (Stanton et al., 2005). The present analysis method could help to define such needs in the realm of driving, helping to equip drivers with a form of 'meta-awareness' of their own propensity towards certain cognitive states in certain situations. For example, driver training could provide coaching and tuition on the need to conduct regular rearward checks on country roads and at junctions (as faster vehicles may be approaching from behind). Infrastructural interventions suggested by this work could involve road signs that do not warn of events ahead, but instead warn of potential events behind (e.g. 'faster traffic approaching behind', 'check mirrors now', etc.).

A further practical intervention is the concept of cross-mode training, an intervention strongly suggested by Maguzzi et al.'s previous work and confirmed by the present findings. This represents best practice in several transport domains. For road transport there is distinction to be made between specific vehicle control skills (e.g. clutch control, hill starts, reversing, etc.) and mode-independent skills (e.g. road and traffic awareness, giving indications, rights of way, etc.). Interventions of this form could take the form of practical training of the latter mode-specific skills using alternative vehicle types, simulations, walk and or talk-throughs. The aim would be to provide practical experience of how different road users interpret the same situation.

The final intervention suggested by the present work relates again to the railway industry and the concept of 'route drivability' (Hamilton et al., 2007). In essence, this is a form of 'analytical prototyping' in which proposed changes in routes, signaling, signage, etc. are tested in terms of driver workload. For road transport, the verbal protocol/semantic network method (in cooperation with other methods) could serve a similar analytical prototyping purpose. The method outputs could be used to ascertain how road situations are interpreted, how physical features could be used to modify that interpretation in favourable ways, and to define cognitively the optimum type and placement of road signs.

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