Cognitive Compatibility of Motorcyclists and Drivers

Guy H. Walker[1], Neville A. Stanton[2], and Paul M. Salmon[3]

[1] School of the Built Environment, Heriot-Watt University, Edinburgh, UK
[2] Transportation Research Group, University of Southampton, Southampton, UK
[3] Accident Research Centre, Monash University, Victoria 3800, Australia
G.H.Walker@hw.ac.uk

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. 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. 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. In this case, no matter how visible a rider may be, if the driver is operating in a situation which is generating a strong stereotypical response 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. We refer to this as cognitive incompatibility.

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 (1979) idea that a relationship exists between people and their

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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 suggests that perceived states are dynamic and evolving. In this paper semantic networks are used as a way of representing such states.

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 & 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. Klein & Hoffman, 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 (2009) and Stanton (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 may contribute towards mental templates which generate strong stereotypical behaviours potentially unfavourable to the latter.

This question will be explored in the current article by creating semantic networks based on verbal commentaries provided by car drivers and motorcyclists using a highly reliable automated process called Leximancer™. Potential incompatibilities will be revealed by differences in the structure and content of these networks.

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 to 35 years old. Mean driving experience was 5.83 years for the car drivers and 5.33 years for the motorcyclists.

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 behaviour. 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.

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.

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. 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.

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 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 traveling 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.

3.2 Structure of Semantic Networks

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 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:

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

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 2 (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:

$$\text{Diameter} = \text{maxuyd}(ni, nj) \quad (2)$$

where d(ni, nj) 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) while 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:

$$\text{Centrality} = \frac{\sum_{i=1;j=1}^{g} \delta ij}{\sum_{j=1}^{g} (\delta ij + \delta ji)} \quad (3)$$

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.

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, 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 was also 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 while word counts increase with hazard incident rate, the prominence of individual concepts tends to decrease (for both road users). Another key structural difference between motorcyclists 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).

3.3 Thematic Analysis

In Leximancer™ 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™. 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 1 presents a summary of the results obtained. Under the null hypothesis it would once more be expected that the matrix of populated cells 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.

Table 1. Summary of results

	Motorway	Major Road	Country Road	Urban Road	Residential Road	Junction
Number of themes increasing in relevance for Motorcyclists	6	4	4	2	1	4
Number of themes increasing in relevance for Car Drivers	5	2	5	4	4	4
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)

Visual inspection of Table 1 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 above on centrality.

4 Conclusion

This short paper has tried to show how a reliable, automated, semantic network creation process, coupled to concurrent verbal protocol data, is able to provide some interesting insights into how different road users experience the same road situations. 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 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. 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. This already 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, Lowe & Hill, 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 and other infrastructure.

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