Exploring schema-driven differences in situation awareness between road users

Exploring schema-driven differences in situation awareness across road users: an on-road study of driver, cyclist and motorcyclist situation awareness

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Abstract

Collisions between different road users make a substantial contribution to road trauma. Although evidence suggests different road users interpret the same road situations differently, it is not clear how road users' situation awareness differs, nor is it clear which differences might lead to conflicts. This article presents the findings from an on-road study conducted to examine driver, motorcyclist and cyclist situation awareness in different road environments. The findings suggest that, in addition to minor differences in the structure of different road users' situation awareness (i.e. amount of information and how it is integrated), the actual content of situation awareness in terms of road user schemata, the resulting interaction with the world, and the information underpinning situation awareness is markedly different. Further examination indicates that the differences are likely to be compatible along arterial roads, shopping strips and at roundabouts, but that they may create conflicts between different road users at intersections. Interventions designed to support compatible situation awareness and behaviour across different road users are discussed.

Practitioner summary

Incompatible situation awareness plays a key role in collisions between different road users (e.g. drivers and motorcyclists). This on-road study examined situation awareness in drivers, motorcyclists and cyclists, identifying the key differences and potential conflicts that arise. The findings are used to propose interventions designed to enhance the compatibility of situation awareness across road users.

Introduction

Road transport-related trauma continues to be one of the leading causes of death and disability throughout the world (World Health Organisation, 2009). Although significant reductions in fatalities and injuries have been made in most motorised countries (Elvik, 2010) a number of complex intractable issues remain. One of these is collisions between different types of road user (e.g. drivers and motorcyclists, drivers and cyclists). For example, an analysis of UK motorcyclist crashes found that their most common cause was other vehicles entering motorcyclists' path when exiting side roads (Clarke et al, 2007). Similarly, the road safety literature suggests that a high proportion of cyclist crashes involve drivers failing to detect cyclists and colliding with them (Wood et al, 2009). Elvik (2010) identifies incompatibilities between different road user groups as one five critical but persistent road safety issues that have to date proved difficult to solve.

Despite forming a substantial component of the road trauma burden, the causes of collisions between distinct road users remain ambiguous. Moreover, it is not clear what countermeasures are the most appropriate. Various studies have examined concepts such as cognitive conspicuity (e.g. Hancock et al., 1990) and the looked-but-failed-to-see error

(Herslund & Jørgenson, 2003), however, there is debate over the factors underpinning these phenomena (e.g. Crundall et al, 2013; White & Caird, 2010) and many solutions have been proposed with a failsafe solution yet to be identified (Clabaux et al, 2012). Further, there has been little investigation of these phenomena using studies of on-road behaviour. Recent research suggests that the ubiquitous Ergonomics concept of situation awareness has a key role to play both in understanding, and preventing, collisions between different road users. Specifically, studies of road user situation awareness underpinned by Neisser's (1976) perceptual cycle model (see Plant and Stanton, 2013) suggest that differences in road user schemata and behaviour, driven by experience, transport mode, and road design, may lie at the root of these conflicts (e.g. Salmon et al, 2013; Walker et al, 2011). Low sample sizes have however thus far limited the generalizability of results, and researchers acknowledge the need for further confirmatory research (Salmon et al, 2013; Walker et al, 2011). This paper presents the findings from a larger scale on-road investigation of driver, motorcyclist, and cyclist situation awareness in different road environments. The study involved assessing situation awareness across participants from each road user group whilst they negotiated an urban route incorporating intersections, arterial roads, roundabouts, and a shopping strip. The aim of the study was to identify the key differences in situation awareness between road users, to pinpoint the causes of these differences, and to identify potential conflicts that arise when road users engaged in the same road situations experience them differently.

Situation awareness and its role in collisions between different types of road user

Situation awareness is a popular ergonomics construct that has received significant attention in safety-related research across many domains. Although various models are presented in the literature, including Endsley's three level model (Endsley, 1995) and Smith and Hancock's

perceptual cycle model (Smith and Hancock, 1995) (see Salmon et al, 2008 for a review), common across most is the aim to clarify how human operators develop and maintain an understanding of 'what is going on' (Endsley, 1995) during complex tasks. The current authors have previously proposed a systems level model of situation awareness (e.g. Stanton et al, 2006) that focusses on how situation awareness is distributed across actors and artefacts in collaborative environments. Similar to Smith and Hancock's model, at the individual actor level this model is underpinned by Neisser's perceptual cycle model (Neisser, 1976; See Figure 1) and emphasises the key role that schemata, or mental templates, play in the development and maintenance of situation awareness (e.g. Stanton et al, 2009). Salmon et al (2012) recently discussed the model in the context of road user behaviour and subsequently defined road user situation awareness as activated knowledge, regarding road user tasks, at a specific point in time (Salmon et al, 2012). This knowledge encompasses the relationships between road user goals and behaviours, vehicles, other road users, and the road environment and infrastructure. Salmon et al (2012) identified the need to clarify what this activated knowledge is, and how it differs, across different road users.
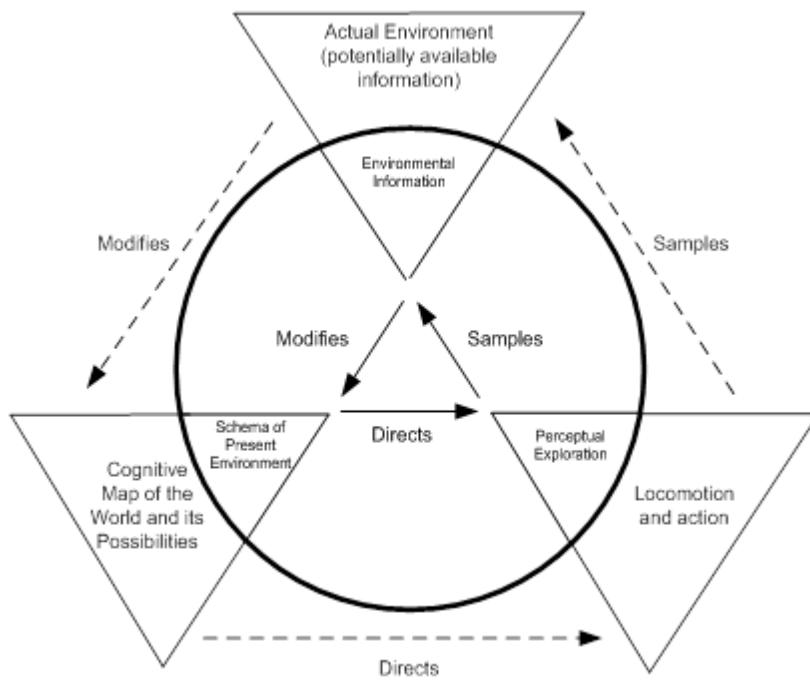
Figure 1. The perceptual cycle (adapted from Neisser, 1976)

This approach to situation awareness appears to offer a useful framework for explaining some of the mechanisms involved in collisions between different road users. The perceptual cycle model argues that humans possess mental templates that, when triggered by contextual conditions, direct perception and behaviour, and ultimately our interaction with the world. This ecological approach suggests that perception is an active, rather than a passive, process and that perception can be viewed as guided exploration in the sense that active schemata direct where road users look and what they expect to see. We understand the stream of activity though the anticipation (and continuous modification of that anticipation) to make sense of the events as they unravel through the interaction.

Relating this to situation awareness it is argued that situation awareness is schema driven in that schemata direct how we interact with the world (i.e. seek information), how we perceive the world, and how we use this to determine the actions required for a given task. Stanton et al (2009) used the genotype phenotype schemata distinction (Neisser, 1976) to show how individuals possess genotype schemata for different situations that are triggered during task performance to form the phenotype. For example, in the road traffic context, drivers possess genotype 'intersection' schemata that become triggered upon encountering intersections. The task-activated phenotype schemata direct and guide drivers interaction with the intersection and perception of it (what their expectations are, where they look, how they interpret information) and how they behave (whether they brake, change lanes, or accelerate through the intersection). The resulting interaction then modifies or confirms the genotype intersection schema which in turn influences behaviour at the next intersection and so on.

Situation awareness obviously plays a key role in collisions between road users as one road user is typically not aware of the other, however, underpinning this are road users schemata, which direct where road users look and how they perceive and interpret information. For example, drivers with little experience of encountering motorcyclists and cyclists at intersections may possess intersection schemata that do not incorporate motorcyclists and cyclists, hence they may not look for them, and even if they do, may not perceive them. This line of thinking adds a further layer of explanation to concepts such as looked-but-failed-to-see errors and weak cognitive conspicuity since it argues that schemata are the primary mechanism underpinning such failures.

A second related component of the distributed situation awareness model is compatible situation awareness (Stanton et al, 2006); that is, the extent to which different team members' situation awareness connects together to support teamwork. Stanton et al (2006), for example, argue that compatibility between different actors' situation awareness acts as the glue that holds complex sociotechnical systems together. This suggests that incompatibilities in situation awareness across road users may also lie at the root of conflicts between them. Since different road users have undertaken distinct forms of training, have had different traffic experiences, and engage in different tasks due to their respective transport mode, it is argued that their situation awareness will be different even when engaged in the same road situations (Salmon et al, 2013; Walker et al, 2011). That is, different road users, operating with their own unique schemata, interact with and sample the environment differently and perceive and interpret the same road situations differently (Salmon et al, 2013; Walker et al, 2011). An important research question then relates to the extent to which these differences in situation awareness are compatible in different road environments and situations.

Preliminary research undertaken by Salmon et al (2013) and Walker et al (2011) has investigated the level of compatibility between different road users' situation awareness. For example, Salmon et al (2013) found that, at intersections, motorcyclist situation awareness was heavily underpinned by information related to avoiding other traffic and the opportunity to filter between traffic queues, whereas driver situation awareness was underpinned by the traffic ahead of the vehicle and the intersection infrastructure (e.g. traffic lights). They argued that these differences are incompatible in that they increase the potential of conflict between drivers and motorcyclists at intersections.

Whilst the studies undertaken by Salmon et al (2013) and Walker et al (2011) are important, both were exploratory in nature and used small sample sizes that limit the utility of their findings. There are therefore two pressing research questions tackled by this paper. First, assuming that situation awareness does indeed differ across distinct road users, exactly how it differs requires clarification. This relates not only to the 'activated knowledge' that road user situation awareness comprises, but also to the way in which road users interact with the road environment in order to generate and maintain situation awareness (i.e. their perception-action cycle). There are notable gaps in the ergonomics literature surrounding what different road user situation awareness comprises in terms of activated knowledge, but also what schemata in different road environments might comprise. Second, the extent to which differences in road user situation awareness are compatible requires investigation. Importantly, understanding the nature of these differences and incompatibilities will support the development of appropriate interventions designed to create safer interactions between road users. It might be, for example, that the effect of making motorcyclists and motorcycles more conspicuous is only minimal if drivers' schemata does not incorporate motorcyclists or support scanning of the area of the road where motorcyclists operate (as found in Salmon et al, 2013).

Describing situation awareness across different road users

Directly measuring mental constructs such as schemata and situation awareness is not possible (Plant & Stanton, 2013). Rather, observable manifestations of schemata, such as behaviour, can be used to make inferences about their characteristics (Plant & Stanton, 2013). The present study used a network analysis-based approach to describe and assess road user situation awareness. This approach has become popular as a way of describing situation

awareness in real world contexts with recent applications in areas such as road safety, (e.g. Salmon et al, 2013; Walker et al, 2011), submarine warfare (e.g. Stanton et al, in press), and air traffic control (Walker et al, 2010). Using this approach, situation awareness networks are constructed using data derived from the Verbal Protocol Analysis (VPA) method, which involves participants 'thinking aloud' as they perform tasks. Based on content analysis of the VPA transcripts, the situation awareness networks depict the information or concepts underlying awareness and the relationships between the different concepts. For example, the transcript extract "the traffic lights are green" would produce the linked concepts 'Traffic lights' and 'Green' as in the traffic light 'is' green. Once the full transcript is analysed an overall network depicting situation awareness as a series of linked concepts is constructed. Mathematical analysis is then used to interrogate the content and structure of the networks. This enables comparison of situation awareness across different actors and scenarios.

On-road study

The aim of the study was to investigate the differences in, and level of compatibility between, driver, motorcyclist, and cyclist situation awareness. Situation awareness networks, constructed based on content analyses of verbal protocols provided by participants whilst negotiating a pre-defined urban test route, were used to describe road user situation awareness. A range of quantitative and qualitative network analysis procedures were then used to analyse the structure and content of the networks. Based on previous research (e.g. Salmon et al, 2013; Shahar et al, 2010; Walker et al, 2011), the hypothesis was that the different road users (drivers, motorcyclists, cyclists) would interpret similar road situations differently. Specifically, the knowledge underpinning situation awareness would be different, both in terms of content (i.e. nodes in the networks) and structure (i.e. connectedness of the

nodes), across the three road user groups studied. Following this, an investigation into the compatibility between road users' situation awareness and the reasons underpinning the key differences in situation awareness was undertaken based on the networks produced.

Methodology

Design

The study was an on-road study using a semi-naturalistic paradigm whereby participants drove an instrumented vehicle around a pre-defined urban route. Drivers drove the Monash University On-Road Test Vehicle (ORTeV), whilst motorcyclists and cyclists completed the route using their own motorcycle or bicycle which was instrumented with video and audio recording equipment. All participants provided concurrent verbal protocols as they negotiated the route. For each participant, situation awareness networks were constructed for four distinct road environments along the route: intersections (15 in total), arterial roads (approximately 6.2kms), a shopping strip (approximately 0.5km), and three roundabouts.

Participants

Fifty eight participants (32 male, 16 female) aged 21-64 years (mean = 37.31, SD = 13.02) took part in the study. They comprised 20 car drivers, 18 motorcyclists, and 20 cyclists. An overview of the participants in each group, including gender, mean age and experience is presented in Table 1.

Table 1. Participant demographics

Road user group	Mean age (SD)	Gender	Mean number of hours typically travelled per week using respective mode of transport (SD)	Years held license	Number who also: a. Drive (with license) b. Motorcycle (with license) c. Cycle
Drivers	34.9yrs (12.53)	10 males 10 females	11.5 hours (5.05)	16.2	a. N/A b. 0 c. 9
Motorcyclists	45.5yrs (12.87)	17 males 1 female	7 hours (5.19)	13.6	a. 20 b. N/A c. 8
Cyclists	32.4yrs (10.42)	15 males 5 females	6.85 hours (5.23)	N/A	a. 18 b. 0 c. N/A

Participants were recruited through a weekly on-line university newsletter and were compensated for their time and expenses. Prior to commencing the study ethics approval was formally granted by the Monash University Human Ethics Committee.

Materials

A demographic questionnaire was completed using pen and paper. A desktop driving simulator was used for the verbal protocol practice component of the study. A 15km urban route, located in the south-eastern suburbs of Melbourne, was used for the on-road study component. The route comprised a mix of arterial roads (50, 60 and 80km/h speed limits), residential roads (50km/h speed limit), and university campus private roads (40km/h speed limit). As described above, four distinct route sections formed the basis for the analysis of road user situation awareness: intersections, arterial roads, a shopping strip, and three roundabouts. Fifteen intersections along the route were focussed on for the intersections analysis component. These comprised a mix of fully signalised (i.e. all turns controlled by

traffic lights), partially signalised (i.e. some but not all turns controlled by traffic lights) intersections, and non-signalised intersection and required seven right hand turns, four left hand turns and four straight through manoeuvres. None of the intersections provided dedicated cycling or motorcycling lanes. The arterial roads component comprised approximately 6.2kms of arterial roads along the route. These had 3 lanes and an 80km/h posted speed limit and did not provide dedicated lanes for motorcyclists or cyclists. The shopping strip section of the route was approximately half a kilometre in length, had a 60km/h posted speed limit, and had shops and car parking spaces running parallel to the road on either side. Finally, three roundabouts formed the roundabout component of the road. All were located in a 40km/h section of the route and required two straight on manoeuvres and one right hand turn manoeuvre from all participants.

Drivers drove the route in the ORTeV, which is an instrumented 2004 Holden Calais sedan equipped to collect various vehicle and driver-related data. A Dictaphone was used to record drivers' verbal protocols. Motorcyclists rode the route using their own motorcycle. Each motorcycle was fitted with an Oregon Scientific ATC9K portable camera, which, depending on motorcycle model was fixed either to the handlebars or front headlight assembly. The ATC9K camera records the visual scene, speed and distance travelled (via GPS). A microphone was fitted inside each motorcyclist's motorcycle helmet to record their verbal protocols. Cyclists cycled the route using their own bicycles. To record the cycling visual scene and the cyclist verbal protocols, the ATC9K portable camera was fitted to the cyclists' helmets, and cyclists wore Imging HD video cycling glasses. All verbal protocols were transcribed using Microsoft Word.

For data analysis, the Leximancer[TM] content analysis software and Agna[TM] network analysis software were used. Leximancer uses text representations of natural language to interrogate verbal transcripts and identify concepts and the relationships between them. The software does this by using algorithms linked to an in-built thesaurus and by focussing on features within the verbal transcripts such as word proximity, quantity and salience. Initially Leximancer looks for words that frequently appear in the text and then uses a weighting procedure to classify frequently appearing words as concepts. Once a list of concepts is identified Leximancer determines how concepts are related to one another by measuring the co-occurrence of concepts within the text. Leximancer thus automates the content analysis procedure by processing verbal transcript data through five stages: conversion of raw text data, concept identification, thesaurus learning, concept location, and mapping of relationships. The output is a network representing concepts derived from the verbal transcript and the relationships between them reflected within the verbalisations. The Leximancer software has previously been used for situation awareness network construction (e.g. Walker et al, 2011) and other studies have found similar outputs when comparing Leximancer[TM] and manual analyses of situation awareness (e.g. Grech et al, 2002). Although manual construction of situation awareness networks is more sensitive to differences across participants, the Leximancer tool is especially important to analyses of this kind since it provides a less resource intensive, reliable and repeatable process for constructing situation awareness networks and removes analyst subjectivity during network creation.

Treatment of the verbal transcripts with Leximancer led to the creation of four networks for each participant (one for each route section). The networks produced were entered into the Agna network analysis software program for content and structural analysis purposes. Agna

is a social network analysis tool which provides a suite of different metrics for analysing

networks (see below for description of the metrics used). An overview of the network analysis

procedure is presented in Figure 2. Example driver, motorcyclist and cyclist situation

awareness networks are presented in Figure 3.
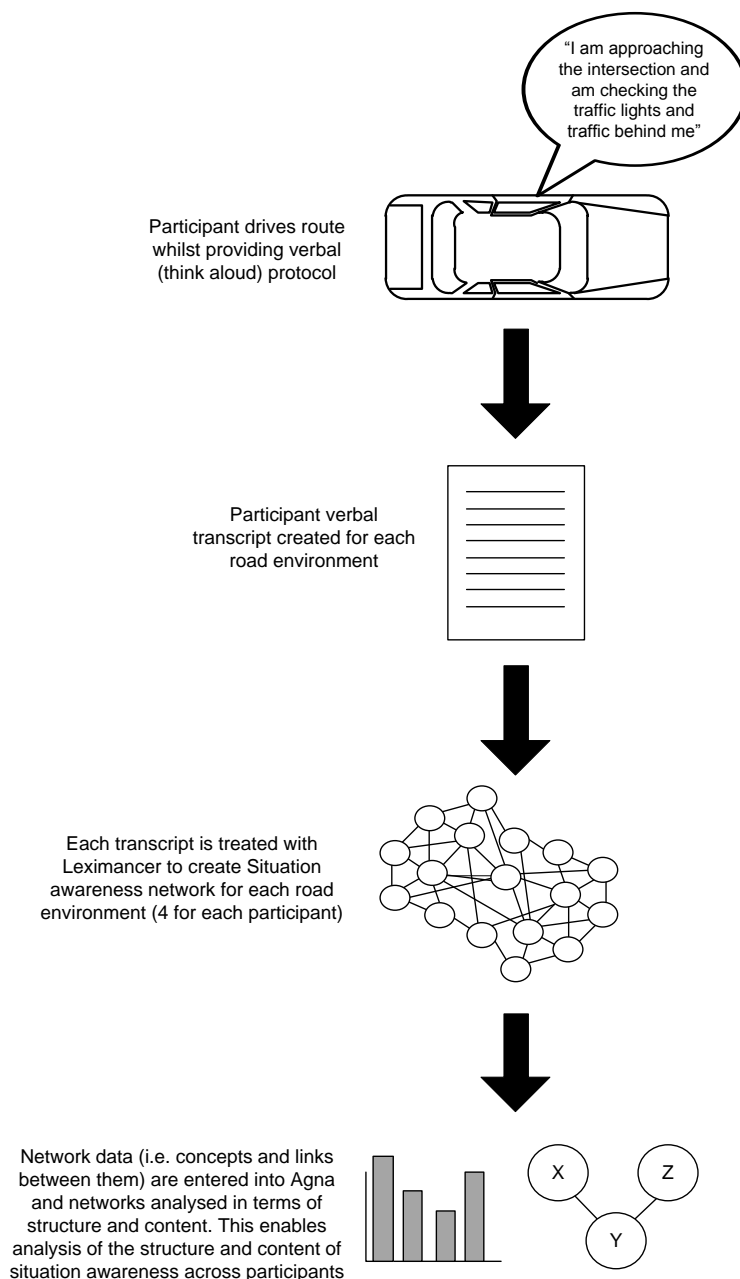
Figure 2. Situation awareness network construction and analysis procedure.
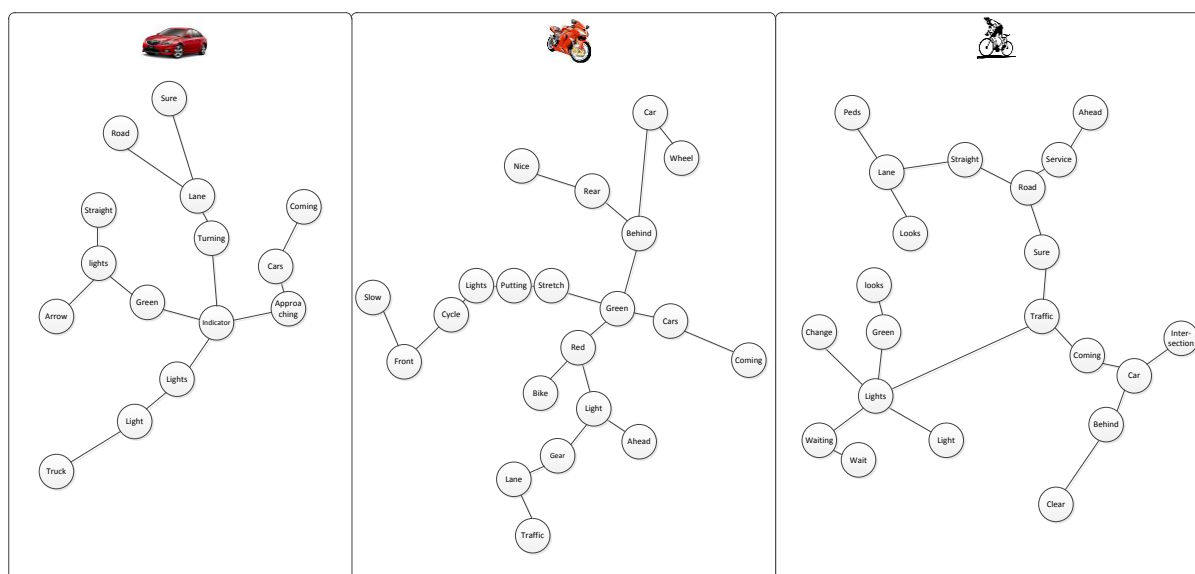
Figure 3. Example driver, motorcyclist and cyclist situation awareness networks for the intersections along the route (adapted from Leximancer).

Procedure

In order to control for traffic conditions, all trials took place at the same pre-defined times on weekdays (10am or 2pm Monday to Friday). These times were subject to pilot testing prior to the study in order to confirm the presence of similar traffic conditions. Upon completion of an informed consent form and demographic questionnaire, participants were briefed on the research and its aims. Following this they were given a VPA training session in which they received a description of the VPA method and instructions on how to provide concurrent verbal protocols. They were then taken to a desktop driving simulator where they were asked to complete a test drive whilst providing a verbal protocol. An experimenter monitored the drive and provided feedback to the participant regarding the quality of their verbal protocol. Following the VPA training, participants were shown the study route and were given time to memorise it. Whilst motorcyclist/cyclist participants were practising the VPA method and

familiarising themselves with the route, a technician fitted the ATC9K camera to their motorcycle or cycling helmet. When comfortable with the VPA procedure and route, participants were taken to their vehicle and asked to prepare themselves for the test. They were then given a demonstration of the video and audio recording equipment, which was also set to record at this point. Following this, the experimenter instructed the participant to begin negotiating the study route. For the drivers, an experimenter was located in the vehicle and provided route directions if necessary. For the motorcyclists and cyclists, an experimenter followed behind (in a car for the motorcyclists, on a bicycle for the cyclists) ready to intervene if the participants strayed off route.

Participants' verbal protocols were transcribed verbatim using Microsoft Word. For data reduction purposes, extracts of each participant's verbal transcript were taken for each road environment (intersections, arterial roads, shopping strip, roundabouts). The extracts were taken based on the video data and pre-defined points in the road environment (e.g. beginning and end of arterial roads). The verbal transcripts were then analysed using the Leximancer content analysis software in order to create the situation awareness networks. The networks were then entered into the Agna network analysis software program for content and structural analysis purposes.

Analysis of Networks

The situation awareness networks were analysed both quantitatively and qualitatively. The quantitative analysis examined network structure and involved using network analysis metrics. Both quantitative and qualitative analysis procedures were then used to examine the

concepts underpinning situation awareness in each of the three road user groups. An overview of the analysis approach is given below.

Network structure

Representing situation awareness in the form of a network provides the opportunity to make inferences regarding the structure and content of situation awareness based on the use of network analysis metrics. A range of network analysis metrics have previously been used in this way to assess situation awareness in terms of network connectedness and the most connected network nodes (e.g. Walker et al, 2009; Stanton et al, in press). It is acknowledged that the metrics were not developed specifically for assessing situation awareness; however it is argued that they provide an appropriate and repeatable way of making inferences regarding differences in situation awareness across the road user groups studied. In the present study, the network density and sociometric status metrics were used.

Network density represents the level of interconnectivity of the network in terms of links between concepts. The formula is presented in Formula 1 below (adapted from Walker et al, 2011).

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

Where:
e = number of links in network

n = number of information elements in network

Formula 1. Network density.

Network density is expressed as a value between 0 and 1, with 0 representing a network with no connections between concepts, and 1 representing a network in which every concept is connected to every other concept (Kakimoto et al, 2006; cited in Walker et al, 2011). It is argued that higher density values are important for situation awareness since they indicate a network in which there is greater integration of concepts than in a similar sized network with a lower density value.

Sociometric status focusses on the concepts (i.e. network nodes) underpinning situation awareness. It provides a measure of how 'busy' a concept is relative to the total number of concepts within the network under analysis (Houghton et al, 2006) and is calculated using the following formula (g is the total number of nodes in the network, i and j are individual nodes and are the edge values from node i to node j).

$$Status = \frac{1}{g-1}\sum_{j=1}^{g}\left(x_{ji} + x_{ij}\right)$$

Formula 2. Sociometric status formula

At the overall network level, a high mean sociometric status value for the overall network indicates that the concepts within the network have high sociometric status values, which is suggestive of a network in which all of the concepts are well connected. It is argued that a

higher mean sociometric status is important for situation awareness since the there is greater integration of concepts than in a similar sized network with a lower mean sociometric status value.

Network content

The content of participant situation awareness at the different road environments was examined by looking at the concepts (or network nodes) underpinning road user situation awareness. First, all of the concepts within the participants' situation awareness networks for each road environment were organised into the following categories and then summed using frequency counts:

1. Traffic lights. Includes concepts related to the traffic lights and their status, such as 'Lights', 'Green', 'Red', "Amber', 'Arrow', 'Turning Arrow' etc;

2. Traffic. Includes concepts related to other traffic in the surrounding environment, such as 'Traffic', 'Cyclist' etc;

3. Locations. Includes concepts referring to a location on the road, such as 'ahead', 'behind', 'side' etc;

4. Physical actions. Includes concepts relating to physical actions being made by the participant or other road users, such as 'change', 'move' 'turn', 'overtake' 'slowing' etc;

5. Cognitive actions. Includes concepts relating to the visual and cognitive activities undertaken by the participants, such as 'checking', 'thinking', 'looking', 'assuming' etc;

6. Communications. Includes concepts relating to communications between road users, such as 'indicating', 'telling' etc;

7. Conditions. Includes concepts that refer to the current road and traffic conditions, such as 'wet', 'slippy', 'debris', 'quiet', 'busy' etc;

8. Speed. Includes concepts relating to the participants and other road users' speed, such as 'speed', 'fast' 'slow' etc; and

9. Other. Includes other concepts not covered by the categories above, such as 'stupid', 'tired' etc.

This provided a total count of the concepts from each road user group across the 9 categories described above.

Second, the concepts that occurred consistently in each road user group at each road environment were identified. This was achieved by pooling all situation awareness concepts within each road user group for each road environment and identifying those concepts that occurred in 50% or more of the participants' situation awareness networks for each road user group at each road environment. The concepts identified were termed 'invariant' concepts.

The two classifications (specific categories and invariants) were then used to create generic road user schemata for each road user group at each road environment. This involved mapping the classifications onto the perceptual cycle. This mapping occurred as follows and is represented in Figure 4:

1. *Invariant concepts*. The invariant concepts were taken to represent genotype schemata and were therefore mapped onto the 'schema of present environment' component of the perceptual cycle;

The concepts relating to locomotion and action and the actual environment were taken to represent phenotype schema and were mapped as follows

2. *Physical and Cognitive actions concepts*. The physical and cognitive action concepts (e.g. checking, looking, thinking, moving) were mapped onto the 'locomotion and action' and 'perceptual exploration' component of the perceptual cycle;

3. *Actual environment concepts*. Concepts classified as those relating to parts of the road environment (e.g. Traffic, Traffic lights, Locations, Conditions) were mapped onto the 'actual environment' and 'environmental information' component of the perceptual cycle.
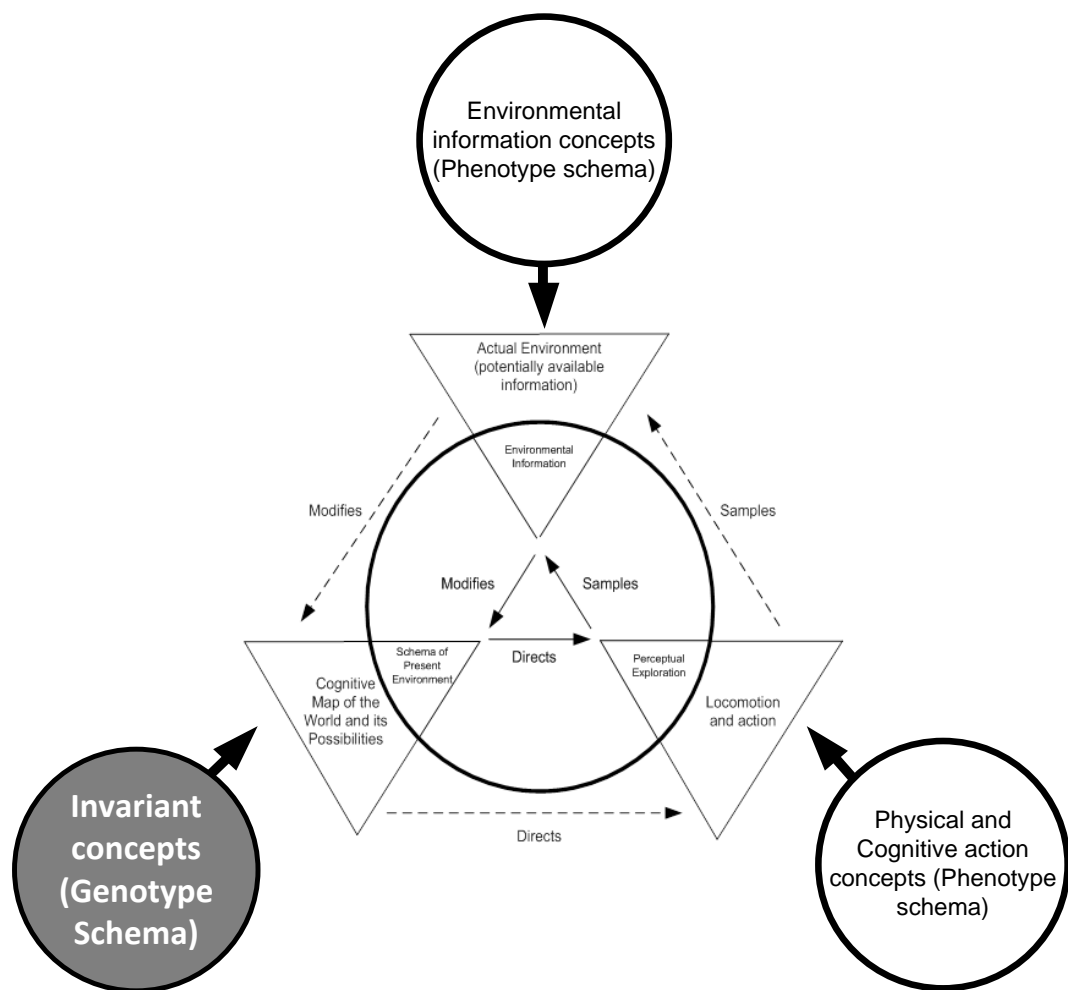
Figure 4. Mapping of situation awareness concepts onto the perceptual cycle.

This process resulted in a generic perceptual cycle representation for each road user in each road environment.

Third and finally, situation awareness content was examined by identifying the 'key' concepts underpinning situation awareness. Specifically, the sociometric status metric was used to identify the most connected concepts underpinning situation awareness for each participant. It is argued that concepts with high sociometric status values represent key concepts since they are highly connected to other concepts within the situation awareness network (Stanton, In Press). In the present study those concepts with a sociometric status value above the mean plus one standard deviation for the network are taken to be key concepts. The key concepts identified for each participant were placed into the concept categories described above, enabling a comparison of the key concepts across road users and road environments.

Results

Network structure

Mean density and sociometric status values for each road user group across the four road environments are presented in Table 2.

Table 2. Mean density and sociometric status values across road user groups and road environments.

Intersections		
	Density	Sociometric status
Drivers	0.54 (*0.14*)	1.89 (*0.86*)

	Density	Sociometric status
Motorcyclists	0.47 (*0.1*)	1.47 (*0.47*)
Cyclists	0.51 (*0.4*)	1.70 (*0.69*)
Arterial roads		
	Density	Sociometric status
Drivers	0.51 (0.14)	1.68 (0.74)
Motorcyclists	0.45 (0.12)	1.42 (0.55)
Cyclists	0.49 (0.12)	1.86 (0.84)
Roundabouts		
	Density	Sociometric status
Drivers	0.88 (0.16)	3.48 (1.25)
Motorcyclists	0.80 (0.21)	3.4 (1.7)
Cyclists	0.76 (0.21)	2.93 (1.18)
Shopping strip		
	Density	Sociometric status
Drivers	0.76 (0.19)	2.73 (1.12)
Motorcyclists	0.73 (0.23)	2.80 (1.29)
Cyclists	0.72 (0.19)	2.64 (1.14)

Although a trend for drivers' networks to have greater density values is apparent, the differences in density across road users did not reach significance at any of the four road environments. The differences in density at intersections and roundabouts, and intersections and the shopping strip were statistically significant (p < .05) as were the differences in density at arterial roads and roundabouts and arterial roads and the shopping strip (p < .05).

Although there were differences in sociometric status values across the road users, none of these were statistically significant. Again there were significant differences across the road environments examined; the differences in sociometric status at intersections and roundabouts and intersections and the shopping strip were statistically significant (p < .05) as

were the differences in density at arterial roads and roundabouts and arterial roads and the shopping strip (p < .05).

Network content – generic schemata for different road users

The mapping of concepts onto the perceptual cycle led to the creation of generic schemata for each road user group at each road environment. For example, the generic intersection schemata for each road user group at intersections are presented in Figure 5. Within Figure 5 the invariant concepts underpin the genotype schemata in each road user group. The phenotype schemata at the locomotion and action and environmental information components of the perceptual cycle are expressed as percentages of the total number of concepts derived from the entire pool of concepts for each road user group at each road environment. For example, if there were a total of 1000 concepts and 100 of these were 'physical action' concepts, this would be expressed as 'Physical actions, 10%' in the diagram. Table 3 presents the generic schemata mapping results in full.
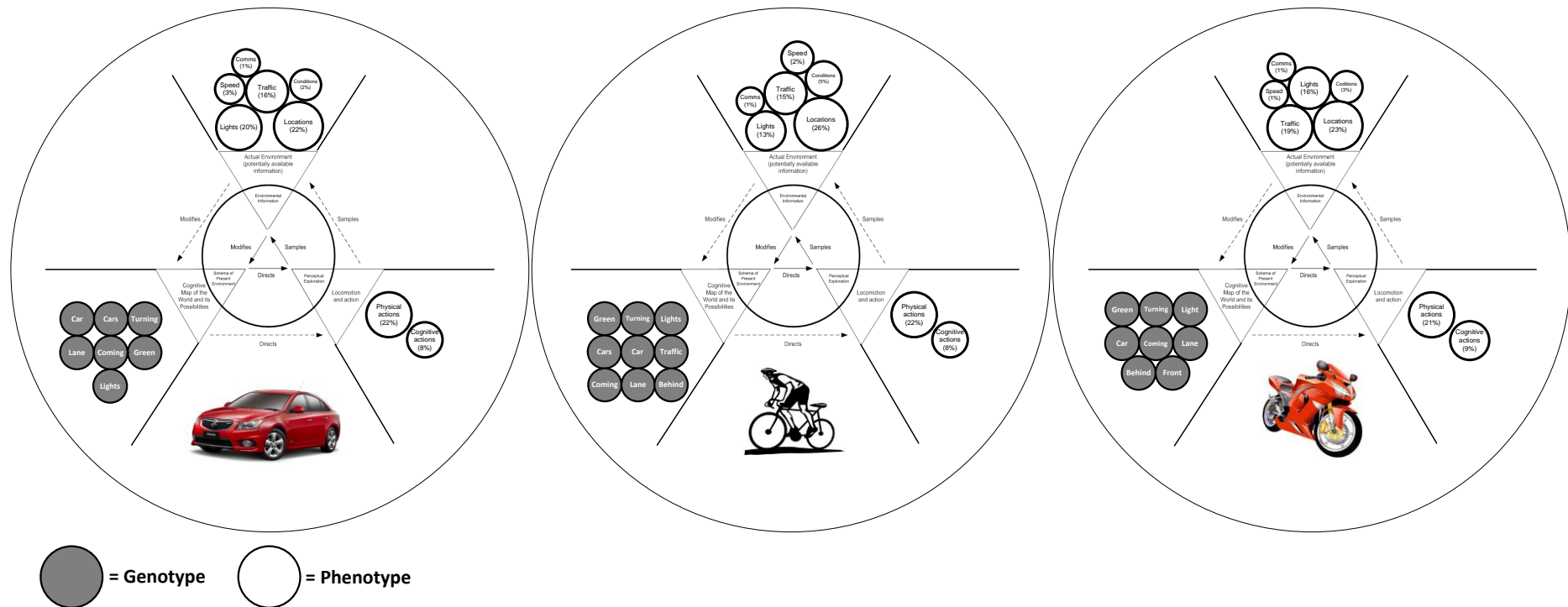
Figure 5. Intersection situation awareness concepts mapped onto the perceptual cycle for each road user group. The phenotype percentages are expressed as a percentage

of the total number of concepts for a particular road user group

Table 3. Concepts mapped onto perceptual cycle across road user groups and road environments.

		Genotype	Phenotype	
Intersections	**Road user group**	**Schema**	**Locomotion and Action**	**Actual Environment**
	Drivers	Car, Cars, Turning, Front, Lane, Road, Coming, Wait, Green, Light, Behind, Intersection, Clear	22% Physical actions 8% Cognitive Actions	22% Locations, 19% Lights, 16% Traffic, 3% Speed, 2% Conditions
	Motorcyclists	Car, Cars, Turning, Front, Behind, Lights, Light, Traffic, Road, Red, Coming, Lane, Hand (side)	21% Physical actions 9% Cognitive actions	23% Locations, 19% Traffic, 16% Lights, 3% Conditions 1% Speed
	Cyclists	Car, Cars, Turning, Lights, Wait, Traffic, Road, Coming, Lane, Front, Behind, Intersection	22% Physical actions 8% Cognitive actions	Locations 26%, Traffic 15%, Lights 14%, Conditions 6% Speed 2%
Arterial Roads	**Road user group**	**Genotype**	**Phenotype**	
		Schema	**Locomotion and Action**	**Actual Environment**
	Drivers	Car, Cars, Turning, Green, Lights, Light, Traffic, Road, Red, Coming, Lane, Front, Behind, Speed	20% Physical actions 10% Cognitive actions	23% Locations, 16% Lights, 15% Traffic, 9% Speed, 4% Conditions
	Motorcyclists	Car. Cars. Turning, Lights, Traffic, Road, Coming, Lane, Front, Behind, Hand (side)	16% Physical actions 9% Cognitive actions	30% Locations, 18% Traffic, 12% Lights, 5% Conditions, 4% Speed
	Cyclists	Car, Cars, Turning, Green, Lights, Traffic, Road, Coming, Lane, Front, Behind, Intersections, Service (Lane), Check	21% Physical actions 11% Cognitive actions	26% Locations, 18% Traffic, 8% Lights, 7% Conditions, 1% Speed
Roundabouts	**Road user group**	**Genotype**	**Phenotype**	
		Schema	**Locomotion and Action**	**Actual Environment**
	Drivers	Roundabout, Cars	25% Physical actions 8% Cognitive actions	26% Traffic, 21% Locations, 5% Lights, 6% Speed, 5% Conditions, 2% Communications
	Motorcyclists	N/A	22% Physical actions 6% Cognitive actions	31% Locations, 22% Traffic, 9% Conditions, 3% Lights, 1% Speed, 1% Communications
	Cyclists	Roundabout, Cars	23% Physical actions 11% Cognitive actions	31% Locations, 24% Traffic, 5% Conditions, 2% Lights, 1% Speed
Shopping strip	**Road user group**	**Genotype**	**Phenotype**	
		Schema	**Locomotion and Action**	**Actual Environment**
	Drivers	N/A	18% Physical actions 11% Cognitive actions	21% Locations, 20% Traffic, 16% Lights, 5% Conditions, 4% Speed
	Motorcyclists	N/A	24% Physical actions 4% Cognitive actions	28% Traffic, 23% Locations, 8% Lights, 3% Communications, 3% Speed, 3% Conditions

| | Cyclists | Car, Cars | 16% Physical actions
8% Cognitive actions | 26% Traffic, 24% Locations, 15% Lights, 5% Conditions, 1% Speed |

The analysis presented in Figure 5 and Table 3 provides a summary of how situation awareness is distributed across the perceptual cycle in terms of road users' genotype and phenotype schemata. The analysis shows, first, that there are differences across the road user groups, and, second, that within road user groups there are differences across the road environments studied.

At the intersections genotype schemata across the road user groups were highly similar, however, notable differences are the inclusion of the 'intersection' itself and the 'clear' concepts in the driver genotype and the inclusion of the 'hand' (side) concept in the motorcyclist genotype. The composition of situation awareness, expressed through the phenotype classification, was also similar across the three road user groups. The majority of concepts related to locations (e.g. 'ahead, 'behind') followed by physical actions (e.g. 'turning', 'stopping' 'going'). Notably, the most frequent location concept for the drivers was 'ahead', whereas the motorcyclists and cyclists also had other frequent location concepts such as 'behind', 'side', 'lane' and 'service lane'. For the drivers, the next most frequent category of concepts related to the traffic lights (19 % of all driver intersection concepts), whereas for the motorcyclists and cyclists the next most frequent was concepts relating to the surrounding traffic. One notable difference at the intersections was that 6% of the cyclists' concepts related to the conditions (e.g. 'quiet', 'busy') whereas this figure was lower for both drivers and motorcyclists.

The genotype arterial schemata were broadly similar to the intersection genotype, however the driver arterial road genotype included the 'speed' concepts, reflecting a continual

monitoring of their own speed, whereas the cyclist genotype included 'service' (lane) and 'check' concepts. The service lane concept reflected the cyclists constant assessment of whether it would be safer to cycle in the service lane as opposed to on the arterial route itself. The check concept reflected the constant requirement for checking behind them for approaching cars. For the phenotype, all road users had a strong focus on locations, physical actions, and the traffic, however, whilst the most frequent category of concept for all three road user groups was locations, the next most frequent for motorcyclists was the surrounding traffic, whereas for drivers and cyclists it was concepts relating to physical actions. In addition, drivers maintained a higher focus on concepts relating to traffic lights along the arterial roads and on concepts related to their own and other traffics speed.

The roundabout genotype schemata were the same for drivers and cyclists, comprising the 'roundabout' and 'car' concepts (the motorcyclist networks did not contain sufficient commonalities in concepts to achieve invariant status). For the phenotype schemata, almost a third of all cyclist and motorcyclist concepts related to locations ('ahead', 'straight'), whereas these concepts represented only around 20% of the drivers overall concepts. Other notable differences included that drivers focussed more on other traffic than motorcyclists and cyclists and also more on speed-related concepts. In addition, 11% of cyclists concepts were related to cognitive actions ('Checking') compared to 8% and 6% for drivers and motorcyclists respectively. Finally, motorcyclists had a greater percentage of concepts relating to the conditions (e.g. 'clear', 'busy').

For the shopping strip, only the cyclist networks contained sufficient invariants to be included in the genotype schemata classification (cars, car). For the phenotype shopping strip

schemata, motorcyclists had a greater percentage of concepts concerned with the traffic and physical actions whereas drivers had a greater percentage of concepts related to cognitive actions and the traffic lights along the shopping strip. The majority of all three road user groups' concepts were related to other traffic, locations, and physical actions.

Key situation awareness concepts

The key situation awareness concepts were identified through examining the sociometric status analysis outputs for the most prominent nodes within the situation awareness networks. The key concepts were coded into the concept categories described earlier. The results of this classification are presented in Figure 6 whereby the key concepts are expressed as a percentage of the total number of key concepts for each road user group in each road environment.
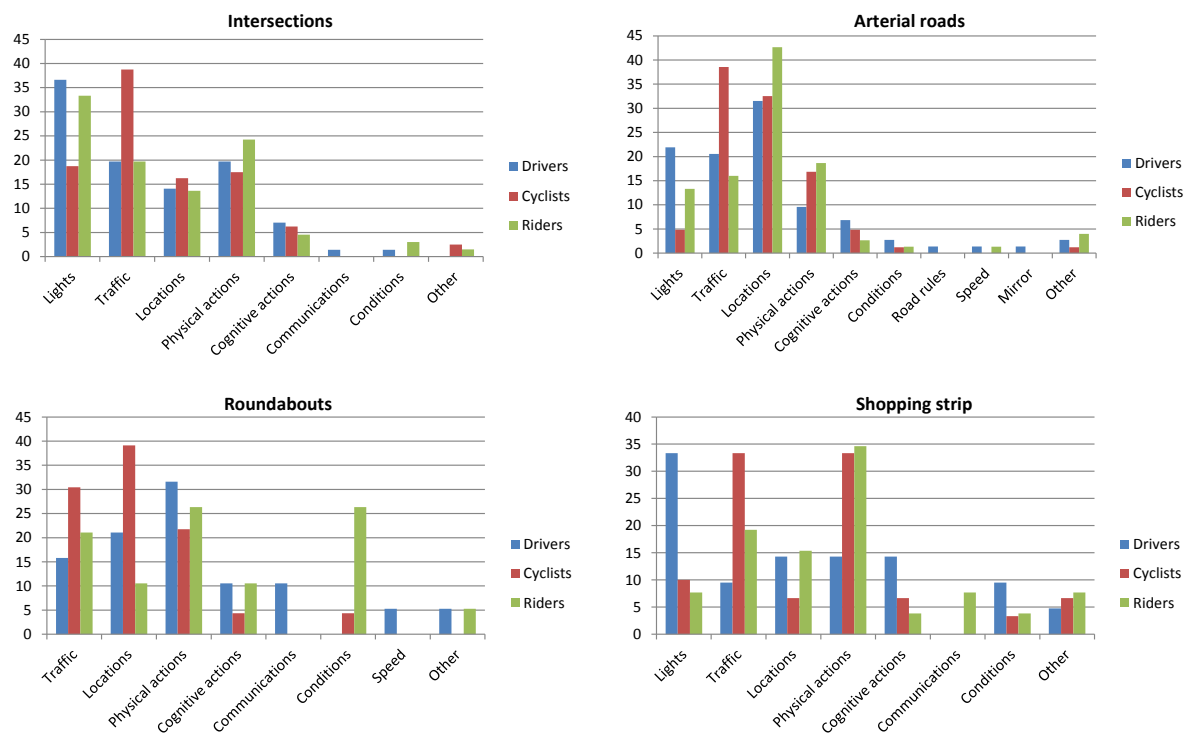
Figure 6. Key situation awareness concepts at intersections, arterial roads, roundabouts and the shopping strip (expressed as percentage of the total number of key concepts for each road user group at each road environment).

The analysis of key concepts shows important differences. Overall, regardless of road environment, cyclist situation awareness is mainly underpinned by a focus on other traffic. For the drivers, it is apparent that the presence of traffic lights shapes their situation awareness significantly, since it becomes their key focus. Motorcyclists are the group most influenced by road environment type, with their key concepts changing markedly across the four road environments studied. For example, along the arterial roads the majority of key

concepts relate to locations around them, whereas along the shopping strip the majority of key concepts relate to their own and other road users' physical actions.

At the intersections, the traffic lights and their status made up over one third of drivers' key concepts, followed by the other traffic (20%), the drivers' and other road users' physical actions (20%), locations in and around the intersection (14%), the drivers' own cognitive actions (7%), communications and the road conditions (both 1.4%). The spread of cyclist key concepts was different, with almost 40% of their key concepts relating to other traffic in and around the intersection and only 19% relating to the traffic lights and their status. Concepts relating to cyclists and other road users' physical actions made up 18% of cyclists' key concepts, followed by locations (16 %), and their own cognitive actions (6%). The motorcyclists' key concepts were more closely aligned to the drivers; however, there were notable differences. Concepts relating to the lights comprised around a third of their key concepts, followed by physical actions (24 %), other traffic (20%), locations (14%), cognitive actions (5%) and the conditions of the road (3%).

Along the arterial roads, the majority of drivers' key concepts were related to locations (32%), traffic lights along the arterial roads (22%), and other traffic (21%). Other frequent key concepts were related to the drivers' and other road users' physical actions (10%), and the drivers' own cognitive actions (7%). For the cyclists, over a third of their key concepts were concerned with other traffic on the road (39%) and almost a third were related to locations on the arterial roads (33%). The next most common were concepts related to the cyclists' own physical actions (17%) followed by concepts concerning the traffic lights and cognitive actions (5%) and the conditions (1.2%). For the motorcyclists, almost half of all key concepts

concerned locations (43%), followed by almost a fifth relating to physical actions (19%). Other motorcyclist key concepts included concepts relating to the traffic (16%), the traffic lights (13 %), motorcyclists' cognitive actions (3%), the conditions (1%) and travelling speeds (1%).

At the roundabouts some notable differences across road users are apparent. Almost 40% of the cyclists' key concepts related to locations, whereas only a fifth of drivers and just over 10% of motorcyclists did. Almost a third of cyclists' key concepts concerned other traffic at the roundabout whereas these concepts only made up around a fifth of the motorcyclists' key concepts and just over 15% of the drivers key concepts. Finally, a quarter of the motorcyclists' key concepts concerned the conditions (e.g. road layout) at the roundabout, whereas these concepts made up just under 5% of cyclist key concepts. Drivers had no key concepts related to the conditions at roundabouts.

Finally the distribution of key concepts was again different across the road users whilst negotiating the shopping strip. The most frequent key concept for drivers was traffic lights-related concepts (33%), whereas light-related key concepts made up only 10% and 8% for cyclists and motorcyclists respectively. A third of cyclist key concepts were related to the traffic, and another third to physical actions. The most frequent key concepts for the motorcyclists were related to physical actions. Interestingly, the drivers had the most key concepts relating to cognitive actions (14% compared to 7% for cyclists and 4% for motorcyclists).

It is also pertinent to examine the differences in key concepts across the four road environments. Cyclist key concepts remained the most stable, with a consistently high

number of key concepts relating to other traffic regardless of road environment. Drivers' key concepts also remained stable, with a high focus on the traffic lights (when present), however, changes were also brought about by the characteristics of the different road environments. For example, along the shopping strip the percentage of key concepts related to cognitive actions (i.e. checking, looking) increased markedly. Of the three road users groups, the motorcyclists were influenced the most by road type, having a variety of prominent key concepts across the four road environments studied. For example, at the roundabouts the majority of key concepts concerned the conditions (i.e. road surface condition), whereas at the intersections the majority concerned the traffic lights, and at along the arterial route the majority concerned locations (e.g. in front, behind, to the side).

Discussion

The aim of this article was to examine the data derived from an on-road study of driver, motorcyclist, and cyclist situation awareness in order determine the nature of any differences in their situation awareness in four different road environments and to identify any incompatibilities that might lead to conflicts between them.

Differences in situation awareness across drivers, motorcyclists, and cyclists

The analysis confirms Salmon et al (2013) and Walker et al's (2011) exploratory study findings that situation awareness is different across road users. Although only small differences in the structure of situation awareness across drivers, motorcyclists and cyclists were found, the content of situation awareness was shown to differ considerably in terms of genotype and phenotype schemata and also the key concepts that underpin situation awareness. Significant differences were also found in the structure and content of situation awareness across the

different road environments studied. The findings suggest then that situation awareness is heavily influenced by schemata, transport mode and the nature of the road environment (e.g. intersection versus arterial road) and that these three factors combine to create differences in situation awareness across distinct road users. The implication of this is that there are various ways in which compatibility between road users can be enhanced, including manipulation of schemata through experience, training and education, and the use of targeted road design interventions.

Incompatibilities in situation awareness

Examination of genotype and phenotype schemata and the key concepts underpinning situation awareness enables judgement to be made on incompatibilities that might lead to conflicts between the different road users. At intersections, genotype schemata were similar across the three road user groups, however, the driver genotype did not incorporate the area behind or to the sides of the vehicle. Moreover, the driver phenotype was heavily focussed on the traffic lights and the area in front of the vehicle. Analysis of the key concepts underpinning situation awareness showed that driver situation awareness was mainly underpinned by the lights and the status of the lights, along with a prominent focus on the intersection itself and the area in front of the vehicle. Although the cyclists and motorcyclists have a strong focus on other traffic and their behaviour in and around the intersection, the drivers do not. This could become problematic when cyclists and motorcyclists operate in intersection areas not incorporated within drivers' genotype and phenotype schemata, such as behind and to the left and right hand sides of the vehicle. This finding is in line with Salmon et al (2013) and also Herslund and Jørgenson (2003) who suggested that a negative effect of driving experience is that drivers may develop fixed routines for search strategies and

information processing that focus on motorised vehicles and the areas that they use. As a corollary, they argued that drivers may unconsciously concentrate on locations where other cars usually operate, and not on the areas that cyclists usually operate. It is concluded then that drivers' limited exploration of the intersection environment is likely to create conflicts with more manoeuvrable and unpredictable road users such as motorcyclists and cyclists.

These findings can be combined with existing literature surrounding concepts such as weak cognitive conspicuity (e.g. Hancock et al., 1990) and the looked-but-failed-to-see error (Herslund & Jørgenson, 2003) to generate a perceptual cycle-based description of conflicts between drivers and motorcyclists and cyclists at intersections. This is represented in Figure 7 where the schemata, perceptual action, and environmental factors creating the conflict are mapped onto the appropriate component of the perceptual cycle. The findings from the present study and the literature suggest that the key factors driving this conflict appear to be the relatively low numbers of cyclists and motorcyclists on our roads, their low level of cognitive conspicuity, road design, drivers' limited schemata and their resulting interaction with intersections. Due to a lack of exposure to cyclists and motorcyclists, some drivers do not appear to be expecting to encounter cyclists and motorcyclists, and if they are, they are not expecting the range of behaviours typically adopted (e.g. lane filtering). As a result, such drivers are either not on the lookout for cyclists and motorcyclists, or are not looking in the appropriate places for them. In the present study driver situation awareness was focussed on the road ahead, their own behaviour, and the lights, and not on the areas of intersections in which motorcyclists and cyclists might be operating (e.g. filtering through the traffic queue). In addition, the literature suggests that in some cases, even when drivers do fixate on motorcyclists they may not perceive them due to factors such as weak cognitive conspicuity

(e.g. Hancock et al, 1990). From a road design point of view, the intersections studied do not support the interaction between different road users. For example, none currently alert drivers to the presence of motorcyclists and cyclists, nor do they offer any protection to the motorcyclists and cyclists as they pass through the intersection (e.g. dedicated cyclist lanes stop prior to the intersection, absence of filtering lanes), which in turn increases their variability in behaviour as they seek the safest way through the intersection.
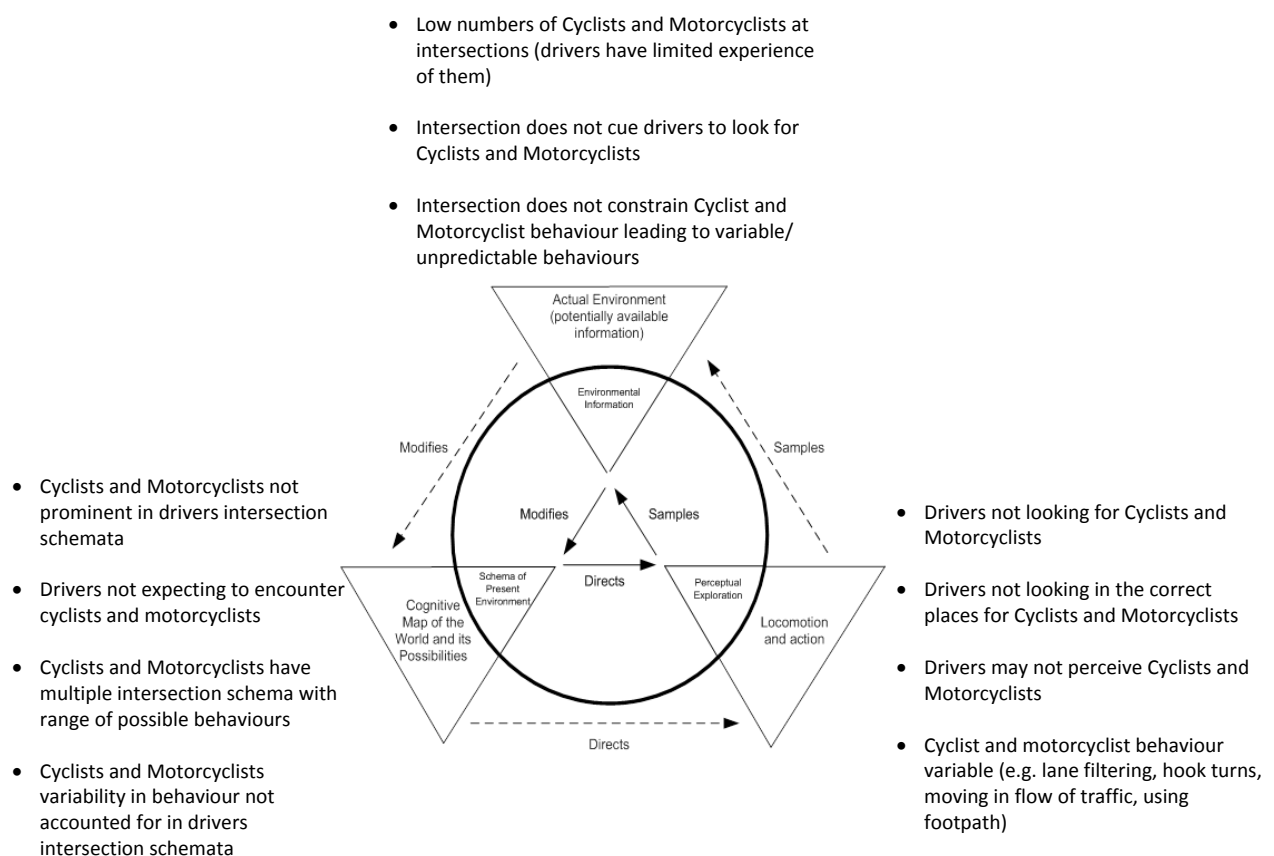
- Low numbers of Cyclists and Motorcyclists at intersections (drivers have limited experience of them)

- Intersection does not cue drivers to look for Cyclists and Motorcyclists

- Intersection does not constrain Cyclist and Motorcyclist behaviour leading to variable/ unpredictable behaviours

- Cyclists and Motorcyclists not prominent in drivers intersection schemata

- Drivers not expecting to encounter cyclists and motorcyclists

- Cyclists and Motorcyclists have multiple intersection schema with range of possible behaviours

- Cyclists and Motorcyclists variability in behaviour not accounted for in drivers intersection schemata

- Drivers not looking for Cyclists and Motorcyclists

- Drivers not looking in the correct places for Cyclists and Motorcyclists

- Drivers may not perceive Cyclists and Motorcyclists

- Cyclist and motorcyclist behaviour variable (e.g. lane filtering, hook turns, moving in flow of traffic, using footpath)

Figure 7. Driver and two wheeler intersection conflict mapped onto the Perceptual Cycle model.

The differences found in the other road environments were broadly found to be compatible. Along the arterial roads, the major differences in genotype schemata were that motorcyclists incorporate a focus on the sides of their vehicle whilst cyclists also focus on potentially moving

into the service lane and also making constant checks of the traffic approaching from behind. The phenotype schemata analysis showed that motorcyclists focussed more on the surrounding locations (e.g. 'front', 'behind', 'side'), drivers focus more on their own speed, and that cyclist situation awareness is heavily underpinned by a focus on other traffic. Drivers did, however, have a strong focus on other traffic and surrounding locations on the road. These differences seem compatible, since the vulnerable road users are constantly on the lookout for drivers, and the drivers are on the lookout for other road users and are cognisant of their own speed. At the roundabouts, both motorcyclist and cyclist situation awareness was underpinned more by concepts concerning surrounding locations, other traffic, and physical actions. Encouragingly, drivers had a strong focus on other traffic, which again suggests that driver, motorcyclist and cyclist situation awareness at roundabout is compatible and well connected. Finally, the differences found along the shopping strip also seem to be compatible. Although drivers again had a greater focus on the traffic lights, they also had a high number of concepts focused on traffic, locations, and physical actions and the most key concepts relating to cognitive actions. This suggests that, although motorcyclists and cyclists are likely to manoeuvre up the traffic queue along shopping strips (Salmon et al, 2013), drivers are expecting this and are on the lookout for them.

Supporting safe interactions between road users

There are a number of different ways in which the level of compatibility between road users' situation awareness and behaviour can be enhanced. First, a number of more simple interventions would seem logical. Primarily these relate to the need to enhance drivers' expectancy and awareness of the presence of motorcyclists and cyclists and of their variable behaviours. Notably studies focussing on the interaction between drivers and motorcyclists

have come to the same conclusion (e.g. Ragot-Court et al, 2012; Mundutéguy & Ragot-Court, 2011). For example, at intersections signage warning drivers to be on the lookout for motorcyclists and cyclists in and around the intersection will be beneficial. In particular warnings that emphasise the high manoeuvrability of cyclists and motorcyclists and the likelihood that they will operate in various parts of the intersection will be useful. Whilst this initially will trigger drivers to look for motorcyclists and cyclists, in the long term the benefit is that drivers will build motorcyclists and cyclists into their genotype intersection schemata. Road design could also be used to limit motorcyclists and cyclists variability in behaviour and to make clear to drivers where in the intersection they will operate. For example, dedicated lanes taking cyclists and motorcyclists through the intersection would not only limit variability in behaviour but would also make clear to drivers that motorcyclists and cyclists are likely to be present at the intersection and also where they will be operating. Another solution is to use interventions to build road users experience and understanding of other modes of transport (e.g. build drivers' motorcycling/cycling experience levels). For example, the provision of driver training focused on developing schemata that incorporate an understanding of other road users' behaviour. Research has shown that drivers who are also licensed motorcyclists are involved in fewer car-motorcycle collisions than car drivers who do not hold a motorcycle license (Magazzù et al, 2006). Also, avenues such as training and education could be used to facilitate the development of shared knowledge about the constraints imposed on different forms of road user. The concept of cross mode training (Maguzzù et al, 2006) where different road users receive training in how other road users interpret the road situation and behave in different situations could be useful for developing anticipatory schema of other road users in drivers. Mundutéguy & Ragot-Court (2011) go further to argue that it could be fruitful to make it a legal requirement that all road users

should hold a license for a powered two wheeler to raise their awareness of the constraints faced by motorcyclists. Further research should examine differences in situation awareness across road users with and without experience of other transport modes (e.g. drivers with motorcycling experience). Previous cognitive conspicuity research has found that car drivers who are also licenced motorcycle riders are involved in fewer car-motorcycle collisions than car drivers who do not hold a motorcycle licence (Magazzù, et al 2006) and that drivers who are also motorcycle riders have a heightened awareness of, and are more attentive towards, motorcycles on the road (Wulf et al, 1989). Whilst this body of research is strong, the issue has not previously been examined through the lens of situation awareness and the perceptual cycle.

More generally the findings highlight the critical role of road design in supporting situation awareness across different road users and in 'connecting' road users. Consideration of different road user situation awareness requirements during the road design process is therefore proposed as an important step in reducing conflicts between different road users. Currently road designs are assessed through a conflict point analysis that focuses on physical pathways through road environments and the potential for road users to come into conflict with one another. It is argued that a failure to consider cognitive conflict points will prevent conflicts between different road users from being solved. The development of situation awareness networks via road user think aloud walkthroughs of road design concepts offers a simplistic low cost avenue for considering different road user situation awareness requirements during the road design process.

The study described did have some minor limitations worth reflecting on. First, a research analyst was present along the route for each participant (travelling behind for motorcyclists and cyclists, travelling in the vehicle for drivers). As a corollary participants were likely behaving optimally without performing traffic violations. Second, the use of Leximancer to build situation awareness networks is less sensitive than when an analyst manually codes the verbal transcripts and hand builds the situation awareness networks; however, due to the large number of participants used was not possible given time constraints to manually build the situation awareness networks. In addition, reliability and repeatability is assured through the use of the Leximancer software. Third, the type and engine capacity of the motorcycles used by participants was not considered in the analysis. Previous research has demonstrated that riders of smaller motorcycles (125cc) differ from riders of medium or large sized motorcycles in terms of their expectations regarding interactions with car drivers (e.g. Mundutéguy & Ragot-Court, 2011). Further research exploring differences in schemata and situation awareness of motorcyclists across different kinds and size of motorcycle is recommended. Fourth, although the verbal protocol analysis methodology has been used previously to study cognitive processes in on-road studies (e.g. Walker et al, 2011) and in other high workload and complex settings (e.g. Kirwan et al, 1996; Sanderson et al, 1989), questions remain over its influence on behaviour during studies (e.g. Hoc and Leplat, 1983). Further testing is therefore required to examine its ecological validity when used for situation awareness assessments. Fifth and finally, participants did not negotiate the route at the same time as one another; rather they negotiated the route under similar traffic conditions. Studying road users' situation awareness when interacting in the same road situation at the same time would provide more valid data on the level of compatibility between them. The

authors are currently preparing to undertake such a study as part of this overall program of research.

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