Investigating the factors influencing cyclist awareness and behaviour: An on-road study of cyclist situation awareness

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Abstract

Situation awareness, ones understanding of 'what is going on', is a critical commodity for road users. Although the concept has received much attention in the driving context, situation awareness in vulnerable road users, such as cyclists, remains unexplored. This paper presents the findings from an exploratory on-road study of cyclist situation awareness, the aim of which was to explore how cyclists develop situation awareness, what their situation awareness comprises, and what the causes of degraded cyclist situation awareness may be. Twenty participants cycled a pre-defined urban on-road study route. A range of data were collected, including verbal protocols, forward scene video and rear video, and a network analysis procedure was used to describe and assess cyclist situation awareness. The analysis produced a number of key findings regarding cyclist situation awareness, including the potential for cyclists' awareness of other road users to be degraded due to additional situation awareness and decision making requirements that are placed on them in certain road situations. Strategies for improving cyclists' situation awareness are discussed.

Introduction

Crashes involving different forms of road user colliding with one another (e.g. drivers and cyclists) represent a long standing intractable road safety problem (Elvik, 2010). The issue is particularly problematic when one of the road users is a vulnerable road user, such as a cyclist. In the case of cyclists, although an increased uptake in cycling for transport has many environmental and physical and psychological health benefits, there are concerns that it will create more trauma derived from crashes involving vehicles and bicycles. It has previously been estimated, for example, that the risk of death when cycling is 12 times higher than when driving a car (Pucher and Dijkstra, 2003; cited in Boufous et al., 2012). Further, a comparison of exposure rates to crash rates reveals that cyclists have a greater exposure to injury and fatal crashes per time or distance than do drivers (Chaurand & Delhomme, 2013).

Although road safety researchers have examined on cyclist crashes, the majority of the research in the area has focussed on overall crash and injury rates or crash characteristics (e.g. time of day) and risk factors (e.g. impairment, helmet use) (Boufous et al., 2012). To date there has been little research examining cyclist cognition and the influence of the road environment on cyclist cognition and behaviour. This leaves many questions unanswered. For example, Boufous et al (2012) reported that the majority of the cyclist crashes in Victoria, Australia during 2004 and 2008 occurred at intersections. Important avenues for further research then include how cyclist cognition and behaviour contributed to the crashes at intersections and further whether the design of the intersections themselves are shaping road user behaviour in a manner that creates collisions between cyclists and drivers.

When these issues are coupled with the fact that road environments have traditionally not been designed specifically to cater for cyclists' needs, understanding cyclist cognition and behaviour represents a pressing requirement for road safety research. In particular, how to support safe cyclist cognition, behaviour, and interactions with drivers through road design is an important line of inquiry for future road safety efforts.

It is argued in this paper that the ubiquitous human factors concept of situation awareness has a key role to play in understanding road user behaviour and preventing collisions between different road users. Situation awareness refers to how humans develop and maintain an understanding of 'what is going on' (Endsley, 1995) and incorporates both the *process* of acquiring awareness and the *product* of awareness itself. In the road context, situation awareness has been defined 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. Despite being a critical commodity for cyclists, there has been no empirical research undertaken to understand what cyclist situation awareness comprises or whether current road environments support or hinder cyclists in their attempts to acquire and maintain an appropriate level of situation awareness for safe and efficient cycling.

This paper presents the findings from an exploratory on-road study of cyclist situation awareness in different road environments. The study involved assessing situation awareness across twenty participants whilst they negotiated an urban study route incorporating intersections, arterial roads and a shopping strip. The aim of the study was to explore what cyclist situation awareness comprised in terms of information derived from the road environment and the resulting 'activated knowledge', to examine differences in situation awareness across the different road environments studied, and to identify issues leading to degraded cyclist situation awareness.

Assessing situation awareness during on-road studies

The study used a network analysis-based approach to describe and assess cyclist situation awareness. This approach involves constructing situation awareness networks using data derived from the Verbal Protocol Analysis (VPA) method, which involves participants 'thinking aloud' as they cycle. The networks depict the information or concepts underlying awareness (nodes) and the relationships between the different concepts (links between nodes). For example, from the verbal transcript line, 'There is a parked car on the left' the resulting nodes and links are presented in Figure 1. This represents situation awareness since the cyclist is aware that there is a parked car on the left in the road ahead.

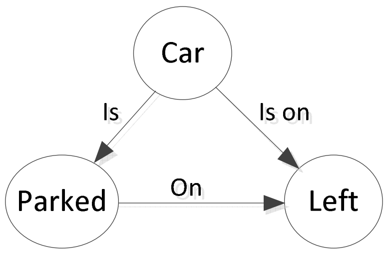

Figure 1. Example situation awareness nodes and links.

Analysis of the verbal transcripts provided by participants enables situation awareness networks to be constructed for different road environments and events. Once the networks are constructed, network analysis metrics are used to interrogate the content and structure of the networks. This enables comparison of situation awareness across different participants and scenarios.

Method

Design

The study was an on-road study in which participants cycled around a pre-defined urban route in the South East suburbs of Melbourne, Victoria. All participants provided concurrent verbal protocols as they negotiated the route. For each participant, situation awareness networks were constructed for three distinct road environments along the route: intersections (15 in total), arterial roads (approximately 6.2kms) and a shopping strip (approximately 0.5kms).

Participants

Twenty participants (15 male, 5 female) aged 18 – 58 years (mean = 32.4, SD = 10.42) took part in the study. The participants were experienced cyclists and at the time of the study cycled on average 6.85 hours per week (SD = 5.23). 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 Human Ethics Committee.

Materials

A demographic questionnaire was completed using pen and paper. A desktop driving simulator was used to provide training in providing concurrent verbal protocols. A 15km urban route 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). Participants 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. In addition, an experimenter fitted with an ATC9K portable camera cycled behind each participant to record the cycling scene from the rear. A Dictaphone was fitted to the cyclists clothing to record the verbal protocols. 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.

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 VPA training in which they received a description of the VPA method and instructions on how to provide concurrent verbal protocols. They were then asked to complete a test drive on a desktop driving simulator whilst providing a verbal protocol and received feedback from an experimenter. This process continued until the experimenter felt that they were capable of providing an appropriate verbal protocol during the cycle. Whilst the participants were practicing verbal protocols the ATC9K camera was fitted to their own bicycle helmet by a technician. Once the VPA training was complete, participants were shown the study route and were given time to memorise it. Participants were then taken to their bicycle and asked to prepare themselves for the test. They were advised to cycle as they would normally cycle and to not modify their normal behaviour in any way during the study. Following this, the experimenter instructed the participant to begin negotiating the study route. An experimenter followed behind on a bicycle to record the cycling scene and 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 for each route section (intersections, arterial roads, shopping strip) were taken from the overall transcript. 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 which auto creates situation awareness networks. The networks were then entered into the Agna network analysis software program for content and structural analysis purposes.

Results

Two different forms of situation awareness network were constructed. First, overall situation awareness networks for all participants in each road environment were constructed in order to derive a generic overview of cyclist situation awareness at intersections and along the arterial roads and shopping strip. This led to the creation of three *overall* cyclist situation awareness networks. Second, individual participant situation awareness networks were constructed for each participant in each of the three environments studied. This led to the creation of 60 *individual* cyclist situation awareness networks.

Overall situation awareness networks

The overall situation awareness networks for each road environment studied are presented in Figures 2, 3 and 4.

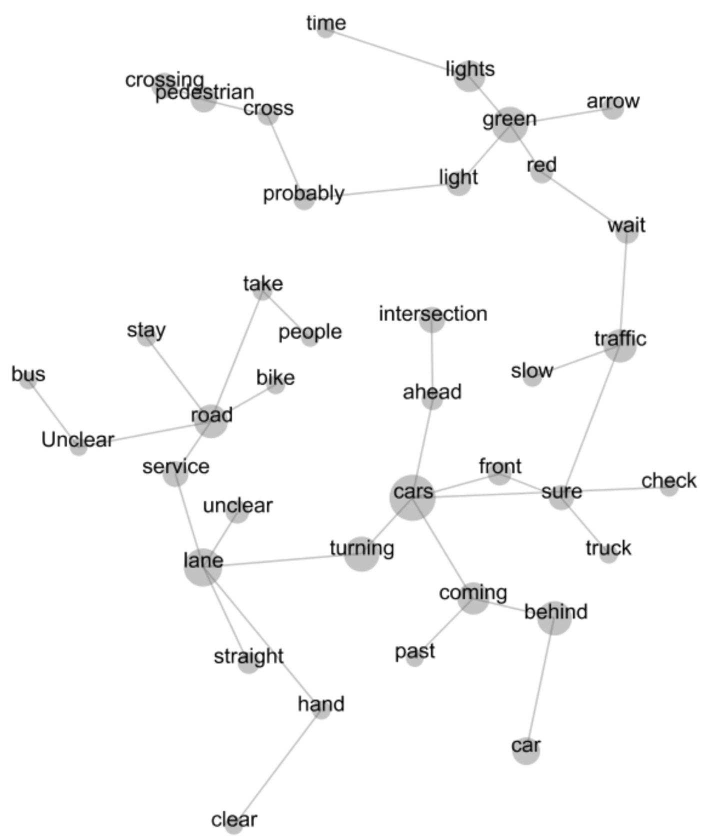

Figure 2. Overall cyclist situation awareness network for intersections.

The overall situation awareness network presented in Figure 2 gives a generic summary of the composition of cyclist situation awareness at the intersections along the route. The network shows that there is a focus on traffic (e.g. 'cars') and its location and behaviour (e.g. 'behind', 'coming', 'turning'), on checking the traffic situation (e.g. 'check'), on the lights and their status (e.g. 'lights', 'green', 'red', 'arrow') and on the road environment (e.g. 'road', 'lane'). Notable concepts within the intersection network are 'service', which represents the service lane, 'lane', and 'crossing' which represents pedestrian crossings in and around the intersections. Further exploration of the verbal transcripts revealed that these concepts are derived from a major decision that cyclists face on approach to intersections regarding which path through the intersection they should take.

Depending on traffic conditions, the intersection itself, and the perceived level of risk, cyclists can either turn right on the road within the flow of traffic, turn right via the pedestrian crossings and along the footpath, or turn right using a ‘hook’ turn whereby they proceed straight on through the intersection, join the traffic queue to the left hand side, and then wait for a green light and proceed straight through the intersection (achieving the originally desired right hand turn). Deciding which way to proceed through the intersection in the present study formed a major decision point for cyclists and incurred the need to assess the intersection itself, the traffic situation, and the level of perceived risk associated with each path through. Cyclist situation awareness on approach to intersections was found to be heavily focussed on information gathering for this decision. Notably, all three ways of passing through intersections for cyclists were observed during the study.

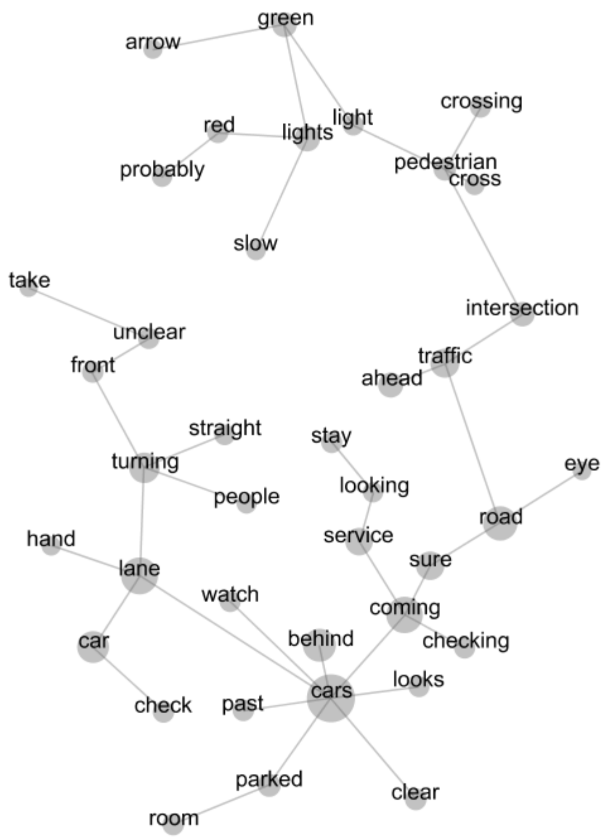

Figure 3. Overall cyclist situation awareness network for arterial roads.

The overall situation awareness network presented in Figure 3 gives a generic summary of the composition of cyclist situation awareness along the arterial roads. Broadly the arterial road network comprises concepts similar to those found in the intersection network; however, there are notable differences. For example, the concepts ‘parked’ and related concepts ‘cars’ and ‘room’ relate to the potential hazard of parked cars on the side of the road and the cyclists being concerned as to whether there is room for them to pass the parked cars without coming into conflict with moving traffic on the road. In addition, the concepts ‘service’ and ‘lane’ derive from the cyclists deciding whether or not to enter the perceived safety of the service lane or to stay on the main road in the normal flow of traffic.

The overall situation awareness network presented in Figure 4 gives a generic summary of the composition of cyclist situation awareness along the shopping strip. The network shows that the cyclists’ situation awareness along the shopping strip was markedly different to the intersections and arterial roads. Interesting features of situation awareness along the shopping strip include the presence of concepts relating to parked cars and their doors (e.g. ‘parked’, ‘doors), which derives from the cyclists constant monitoring of the threat of car doors being opened directly in front of them, and also the presence of pedestrian-related concepts derived from their constant monitoring of pedestrians in and around the shopping strip.

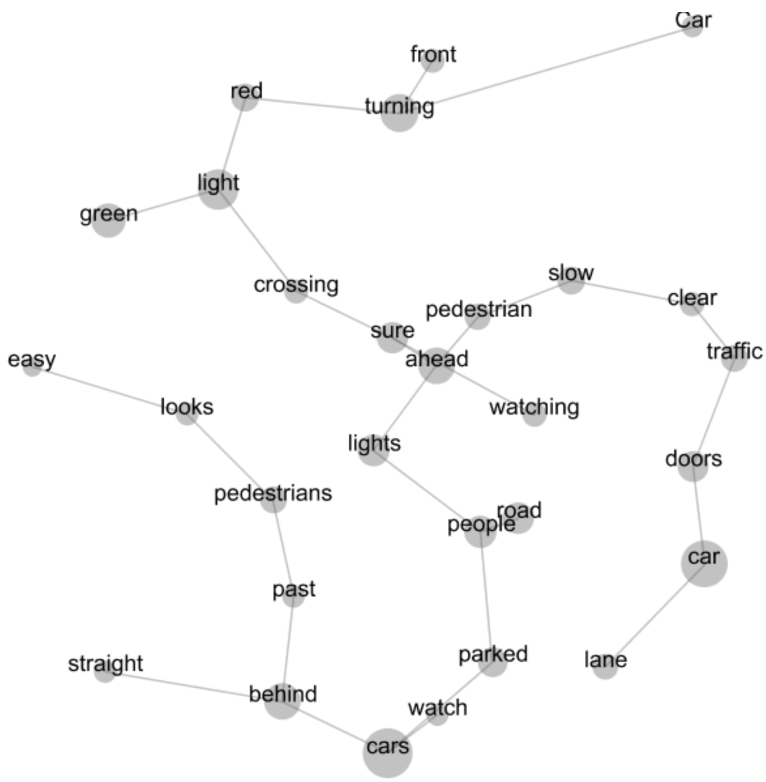

Figure 4. Overall cyclist situation awareness network for the shopping strip.

Individual situation awareness networks

The 60 individual networks were further examined by coding the concepts into concept categories. The classification included invariant concepts (i.e. those present in over half of the participants networks) and categories surrounding physical and cognitive actions, locations on the road (e.g. front, behind), time, risk, traffic etc. For example, the concept category ‘lights’ refers to all concepts related to traffic lights along the route, such as ‘lights’, ‘red’, ‘green’ etc. Frequency counts of the concepts within each category were then conducted. Percentages referring to the total percentage of concepts within each category expressed as a proportion of the total number of concepts for that road environment were then calculated.

The findings from this process were subsequently used to create generic cyclist phenotype schemata for each road environment. Stanton et al. (2009) used Neisser’s perceptual cycle model to describe the schema driven nature of situation awareness, arguing that genotype and phenotype schemata drive, and determine the content of, situation awareness. For example, in the road traffic context, cyclists possess genotype ‘intersection’ schemata that become triggered upon encountering intersections. The task-activated phenotype schemata direct and guide cyclists 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.

Generating generic cyclist phenotype schemata for the three road environments involved mapping the concept classifications onto Neisser's perceptual cycle model. This was achieved by considering the concepts relating to *locomotion and action* and the *actual environment* to represent phenotype schema. 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, whilst concepts classified as 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. This process resulted in a generic phenotype schemata representation for cyclists at each road environment (See Figure 5).

Overall, the phenotype classifications demonstrate that, regardless of road environment, the composition of cyclist situation broadly comprises activated knowledge related to cyclists own and other road users' physical actions (i.e. what the cyclist and other traffic are doing), other traffic generally (e.g. drivers, pedestrians), cognitive actions (e.g. checking, looking), locations in the road (e.g. in front, behind, to the sides, lanes), important road infrastructure and environment features (e.g. the traffic lights, road, road names), the conditions (e.g. wet, busy, slippery), time, level of risk, and communications (e.g. other road users communicating intentions). A notable finding from the analysis is that cyclist situation awareness includes a threat assessment component and a safest path component whereby they are constantly on the lookout for the safest path through different road environments (e.g. which path to take through intersections, whether or not to use the service lane or footpath, assessment of door threats).

Differences in phenotype schema were identified across the three road environments. At the intersections, a quarter of all situation awareness concepts related to physical actions (e.g. 'riding', 'cycling', 'turning', 'stopping', 'clipping in') and around 15% related each to traffic lights and their status and other traffic (e.g. 'cars', 'pedestrians'). Road environment related concepts (e.g. 'intersection', 'road', 9%) and cognitive actions (e.g. 'checking', 'deciding', 8%) were the next most common concepts, followed by concepts relating to lane, areas (e.g. 'front', 'behind'), conditions, risk, and time.

The arterial road networks produced a similar spread of concepts; however, traffic light-related concepts dropped to 8% and cognitive action-related concepts increased to 11%. Other concepts achieved similar percentages; however, notable inclusions in the arterial road networks included concepts relating to the footpath and service lane (3%), space (as in 'is there enough space to get past, 2%), and the doors of parked cars.

More differences are present in the shopping strip phenotype. Here concepts relating to other traffic were the most prominent (23%), with physical actions dropping to 20%. Notably, concepts relating to space (6%), doors (4%) and the area behind the cyclist (6%) were more frequent along the shopping strip networks. In addition, a new category of concepts relates to the 'shops' along the strip (shops, 1%).

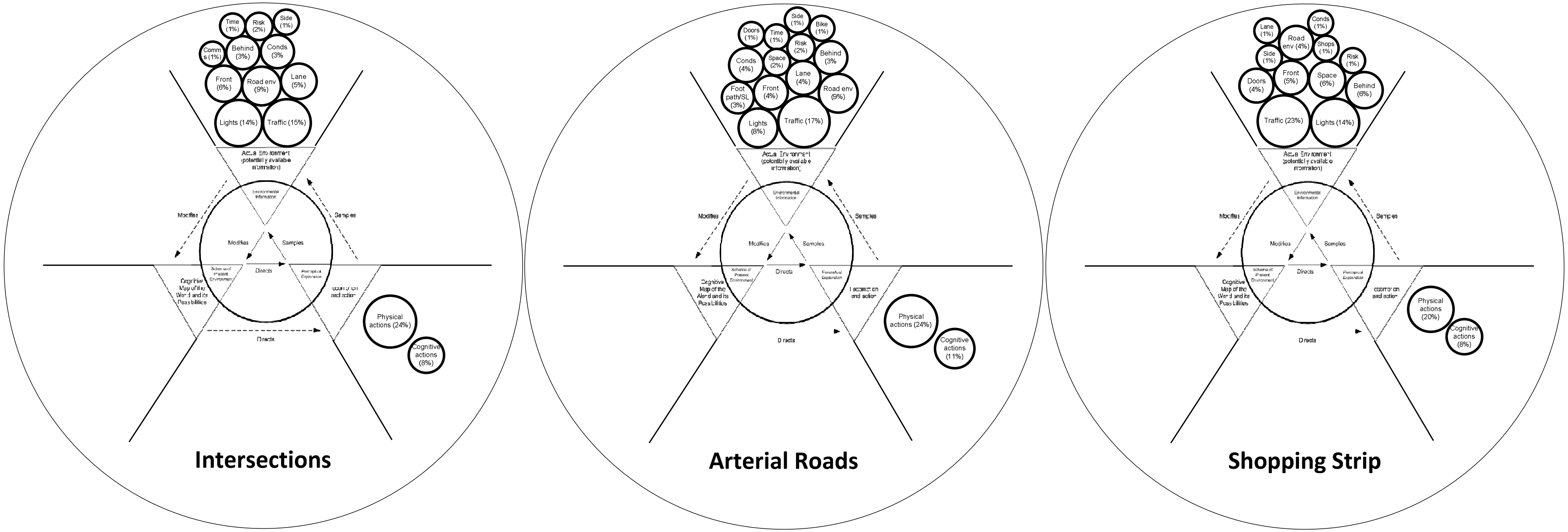

Figure 5. Summary of concepts within individual cyclist situation awareness networks. Number of concepts in each category are expressed as a percentage of the total number of concepts for each road environment.

Discussion

The aim of this paper was to present the findings from an exploratory study of cyclist situation awareness. The findings reveal interesting features of cyclist situation awareness along with issues that could be adversely influencing cyclist situation awareness, behaviour, and ultimately cyclist safety.

Cyclist situation awareness

First, the analysis revealed that broadly, cyclist situation awareness comprises activated knowledge related to cyclists own and other road users' physical actions, other traffic, cognitive actions, locations in the road, road infrastructure and environment features, the conditions, time, level of risk, and communications. Whilst this is not groundbreaking, it reveals the generic make up of cyclist situation awareness and potentially provides a template for training novel cyclists in acquiring appropriate levels of situation awareness during on-road cycling. In addition, this information could be used in design efforts designed to support cyclist situation awareness. For example, the analysis highlights the importance for cyclists to engage in a continual risk assessment process including assessing the risk imposed by elements of the traffic situation including other traffic and the conditions (e.g. road surface, weather). The introduction of novel technologies or road design features to support this process would therefore likely be beneficial.

Second, the analysis indicates that cyclist situation awareness includes some notable features that require both further investigation and support through road design. For example, concepts relating to assessment of risk and threats were found across the different road environments, suggesting that threat assessment forms an important part of cyclist situation awareness (e.g. continual assessment of parked car doors). Further, a safest path component was also identified, relating to the process of assessing and selecting the safest path through different road environments (e.g. which path to take through intersections, whether or not to use the service lane or footpath along arterial roads). These features are interesting both in that they represent an additional level of workload over and above what other road users (e.g. drivers) experience and because they make cyclists unpredictable to other road users, since they have a range of paths that they make take at any given time. At intersections for example, they have a range of paths through (i.e. hook turn, in normal flow of traffic, filtering, on the footpath and via pedestrian crossings) and the timing of path selection is highly variable (ranging from a significant distance prior to the intersection to immediately before the intersection to at the intersection itself). Also notable is that these path decisions often take place in high traffic and complex situations in which there are a number of other important and safety critical situation awareness requirements. Finally, it is also notable that these features of cyclist situation awareness are design induced in that the way in which road environments are designed creates the additional workload and decision requirements. For example, the presence of parking in close proximity to cycle lanes brings with it the requirement to constantly monitor parked car doors and predict when doors might be opened by unaware drivers. The role of road design in supporting, rather than inhibiting cyclist situation awareness is therefore put forward as a key area for further research. Consideration of cyclists' situation awareness during road design efforts is also recommended as a key requirement for future road design efforts.

System redesign

One of the aims of the analysis presented was to identify opportunities to create interventions designed to support cyclist situation awareness, behaviour, and safety. Although the study was exploratory on nature, the findings suggest that there are various avenues that can be pursued. The level of flexibility afforded to cyclists on roads is a key issue as it creates a decision load in already complex road environments (e.g. intersections) and makes them unpredictable to other road users. Supporting cyclists thus involves aiding the decision making process, reducing their unpredictability in high risk areas such as intersections, and/or making other road users aware of their range of possible behaviours. For example, the use of continuous and dedicated cycling lanes through intersections could potentially support cyclists in choosing their path through the intersection early and would also increase the likelihood that they would stick with their choice throughout the intersection. It would seem also that measures should be taken to make other road users (pedestrians, drivers) more expectant of cyclists' range of behaviours. At intersections, for example, drivers need to appreciate that cyclists may make major manoeuvres in close proximity to the intersection, in some cases even from the footpath or service lane along three lanes of traffic into right hand turn lanes. The use of cross mode training has previously been raised as a way of developing anticipatory schema that supports perception of other distinct road users (e.g. Maguzzi et al., 2006; Walker et al., 2011). Cross mode training incorporating both cyclist and motorcyclist training for drivers is likely to increase their expectancy levels regarding cyclist and motorcyclist behaviours at intersections. Study of drivers with high levels of cycling experience may represent a first step in this process as they may reveal that driver-cyclists are demonstrate an expectancy for different cyclist manoeuvres and the range of possible cyclist behaviours. There is also a clear role for road design, with dedicated cycling lanes (on the road and on the footpath) and signage warning drivers of the presence of cyclists and the likelihood that they will make major manoeuvres in different road environments such as intersections. In addition to the interventions proposed, testing of new training initiatives and road designs for their effects on cyclist situation awareness and behaviour are recommended.

As an exploratory study the analysis had some notable limitations. First, the study used a small participant sample size. Caution is urged, therefore, before the results are generalised to the overall road user population. Second, the use of advanced data collection platforms such as eye tracking devices would enable more robust assessments of cyclist situation awareness. Future studies incorporating eye tracking devices are planned by the research team.

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