Factors involved in cyclist fatality crashes: a systematic literature review

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Abstract

In this study, a systematic review was undertaken to identify the factors that contribute to cyclist fatality crashes. The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Protocols 2015 (PRISMA-P) and examined original, peer-reviewed and non-peer-reviewed publications indexed in 10 databases from their inception to November 2014. Contributing factors were identified and analysed using the four pillars of the Safe System approach: safe people, safe roads and roadsides, safe speeds and safe vehicles. In total, 71 papers were included and 52 contributing factors were identified. The review highlights that many system-wide factors that contribute to cyclist fatality crashes have been identified in the literature. Specifically, the majority of factors related to the road user (61.5%), followed by the road and roadside (19.2%), vehicle characteristics (13.5%) and speed (5.8%). Notably, the majority of crashes examined in the literature involve a motor vehicle, it is not known how these crash factors translate to non-vehicle or off-road cyclist fatality crashes. Despite the relatively high involvement of behavioural factors as contributors, the Safe System framework supports a multi-factorial approach to countermeasure development to prevent future cyclist fatality crashes.

1. Introduction

In Australia, in the decade from 2003-2012, an average of approximately 32 cyclists died annually (Bureau of Infrastructure 2013). In 2013, cyclist deaths peaked with 50 fatalities (Bureau of Infrastructure 2014). Every transport death impacts the family and friends of the deceased as well as people involved in or who witnessed the crash. There is also a substantial economic cost of human loss; cyclist deaths in 2013 and 2014 alone have been estimated to have incurred an economic cost of A$228 million (Bureau of Infrastructure 2006). The level of cyclist trauma is a significant concern as Australia has strong policy support for increased cycling participation. At a national level, the overarching vision of the current National Cycling Strategy is to double cycling participation by 2016 (Austroads 2010). The challenge is how to achieve greater cycling participation without simultaneously increasing cyclist road trauma.

From a theoretical perspective, road safety in Australia is underpinned by the Safe System approach. This conceptual framework takes into consideration system-wide factors categorised into four quadrants: safe people, safe roads and roadsides, safe vehicles and safe speed. However, this approach has not been widely applied to the study of cyclists (Johnson 2011). Typically the analysis of cyclist crashes focuses on the behaviour of the road users involved (safe people), with less consideration given to the role of broad system factors (safe roads and roadsides, safe vehicles and safe speed). This literature review has not identified a systematic analysis of the system-wide factors in cyclist fatality crashes. However, an in-depth understanding of all potential contributing factors is critical for informing the design and development of countermeasures to prevent cyclist fatalities.

To address these gaps, the aim of this study was to conduct a systematic review to identify all factors that contributed to cyclist fatality crashes reported in the published literature and to consider those factors within the Safe System approach.

2. Method

The review was conducted in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses for Protocols (PRISMA-P) statement (Moher et al. 2015). The following scientific databases for the disciplines of transport and injury prevention were searched from their inception to November 2014: Cochrane Database of Systematic Review; Compendex; EBSCO; EMBASE; Informit; OVID – Medline; OVID – Transport; Scopus; TRID; and Web of Science. Three research concepts were derived by the authors: "bicycle/cyclist"; "death"; and "crash" and key terms associated with these concepts were developed (Table 1). These terms were grouped using the Boolean operators 'and'/'or'. The full search with the final research concepts and key terms was conducted on 11 November 2014 (MJ).

Table 1. Master list of research concepts and key terms

Concept 1 – Bicycle/Cyclist	Concept 2 – Death	Concept 3 – Crash
bicycl*	mortal*	crash*
bik*	death*	accident*
cyclist*	fatal*	collid*
cycling		collision*

2.1 Data: eligibility criteria, extraction and analysis

The eligibility criteria included: English language, results disaggregated by outcome (fatal or other injury levels), road user and at least one contributing crash factor. Studies of aggregated data were excluded because of insufficient cyclist fatality crash detail. Factors were grouped into the four Safe System approach pillars: safer people, safer road and roadsides, safer speeds and safer vehicles. Non-peer-reviewed literature was included as it provided broader, more detailed descriptions of the crash circumstances than peer-reviewed literature alone. Publications were categorised into three groups: white (peer-reviewed journal articles); grey (reports and documents generated from official data but not peer-reviewed) and dirty (popular media).

Two authors (MJ, CM) reviewed all titles and abstracts to identify publications for inclusion and disputed publications were independently adjudicated (LB). The authors reviewed the publications and extracted the following data: authors; year; title; study aim; article type (white, grey, dirty); country, state/province, county; years of data collection; research design; data analysis; comparison group; outcome (fatal, serious injury, minor injury); crash location (all, on road, off road); age; sex; total deaths reported; crash types; contributing factors people; contributing factors vehicle; contributing factors speed; contributing factors roads and roadsides; risk factors other; summary of main findings; articles identified from bibliographic review, and; data analysis method used.

Extracted data analysed using IBM SPSS Statistics 22. A descriptive statistical analysis was conducted to report: the publication characteristics; presence and contribution of factors outlined in the Safe System approach (people, roads and roadsides, vehicle and speed). Statistically significant differences between categorical variables were calculated using Pearson Chi-Square tests.

3. Results

3.1 Publication selection

The combined searches yielded 11,874 publications, which was reduced to 3,955 after duplicates were removed. Following a review of the title and abstract, this was reduced further to 186 publications. A full text review, including a manual bibliographic review, identified 71 articles eligible for inclusion (Figure 1). See Table 2 for details of included publications. The 71 publications included in the review were published between 1969 and 2015 primarily in developed countries. This comprised publications from the United States of America (n=23), the United Kingdom (n=19), Australia (n=7), 3 publications from each of Finland and France, 2 publications from each of Canada, China, Denmark, Germany and Sweden, and 1 publication from each of Austria, Czech Republic, Italy, Japan, the Netherlands and Norway.

The majority of publications were peer-reviewed journal articles (white literature) (n=32), 20 were non-peer-reviewed newspaper articles (dirty literature) and 19 were non-peer-reviewed reports (grey literature). Amongst the 32 peer-reviewed journal articles, retrospective study designs comprised used included: 25 case series studies, 5 case reports and 2 case-control studies. The white literature was largely based on police (30.3%) and coronial data (27.2%), the grey literature also used police reports (31.5%) and FARS (26.3%) the US Fatality Analysis Reporting System. All FARS reported crashes occurred on a public roadway and involved a crash with a motor vehicle that resulted in the fatality of a motor vehicle occupant or non-occupant within 30 days of the crash(Health Indicators Warehouse 2010). Of the dirty literature, the majority was based on media reports (55.0%) and court proceedings/findings (25.0%). Other data sources used included GIDAS, the German In-Depth Accident Study(Orsi et al. 2013) and the Queensland Child Death Case Register(Fraser et al. 2012) which reviews the deaths of children aged under 18 years by a panel of experts. The majority of publications (61, 85.9%) examined on-road crashes only, 9.8 percent (n=7) examined both on-road and off-road, 1 study examined off-road crashes and 2 studies did not specify the crash location.

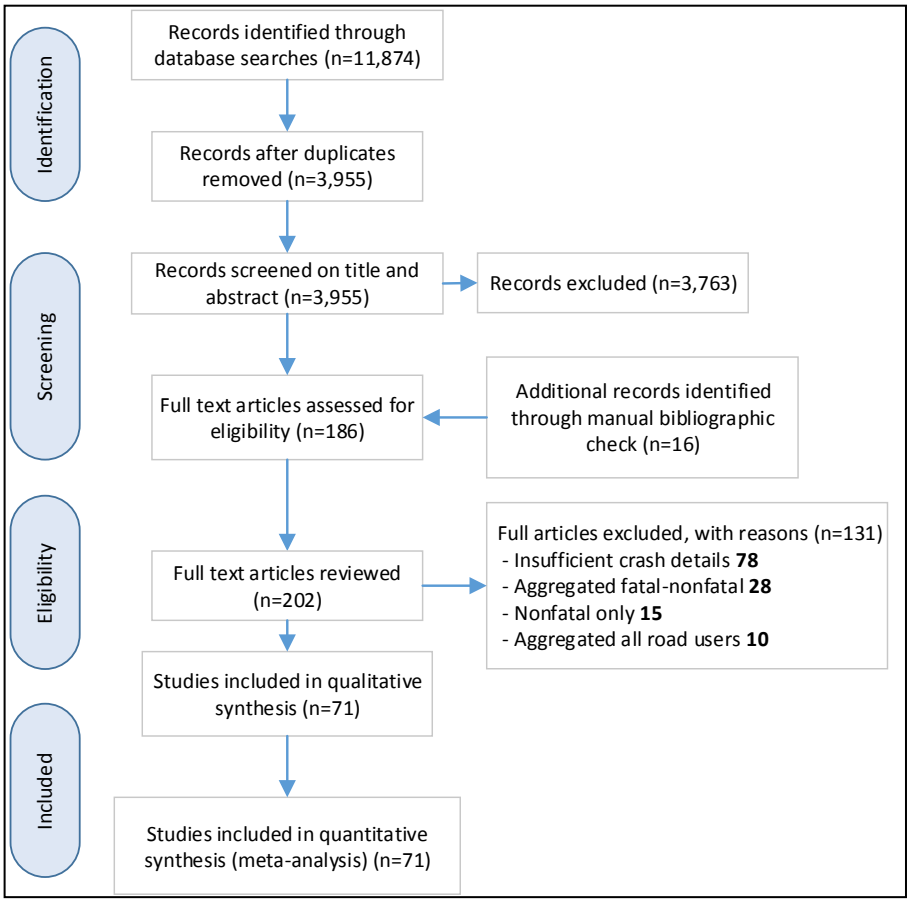

Figure 1. Publication identification, screening, eligibility and inclusion

3.3 Publication findings

In total, 52 discrete factors were identified in the literature as being involved in cyclist fatality crashes (see Table 3). The majority of factors related to the behaviour of the cyclist and the counterpart involved in the crash (safe people: 32 factors; 61.5%), followed by the road and/or roadside (10 factors; 19.2% each), the vehicle (7 factors; 13.5% each) and three factors (5.8%) related to excessive speed by the road user or specific mention of a high posted speed limit contributing to the crash. Two contributing factors outside the Safe System approach were identified as contributing to cyclist fatality crashes; these were categorised as Other (weather, traffic volume). The majority of publications reported the involved factors without any

statistical analysis (61.0%), a third used descriptive statistics (36.2%) and the remainder conducted statistical analysis (2.8%).

3.3.1 Safe System factors – Safe People

The majority of factors identified in the literature were within the safe people category and related to behavioural factors of the cyclist and/or the counterpart(s) (61.5%).

Personal protective equipment: Helmets were the primary focus, particularly use/non-use (53.5%) with widespread support for helmet use (Got 1993, Sjöegren et al. 1993, Bajanowski et al. 1994, Bernhoft 1994, Maki et al. 2003, Kelkka and Toivonen 2011, Clarke 2014) associated with a decreased probability of a fatal outcome (Oström et al. 1993, Kim et al. 2007, Fredriksson et al. 2012). High visibility clothing was identified as important to increase cyclists' conspicuity and non-use was considered contributive in low light/dark crashes (Attewell and Dowse 1992, Cycling Weekly 2008, Daily Mail 2010).

Impairment: Substance misuse was the most frequently identified cause of impairment. Excessive alcohol consumption and drug used was noted by over half the publications (57.7%). There was a consensus about a relationship between intoxication and cyclist fatality (Cooke et al. 1993, Nicaj et al. 2009, Fraser et al. 2012) with a greater probability of fatality, particularly when the driver was intoxicated (Olkkonen 1993, Kim et al. 2007). Other impairments included health- (Klintschar et al. 2003, Akhtar et al. 2010) and age-related impairment (Olkkonen 1993, Bajanowski et al. 1994, Bernhoft 1994), and temporary impairment states (e.g. distraction, inattention (Bicycle Retailer & Industry News 2008, Keigan et al. 2009, Akhtar et al. 2010, Clarke 2014) fatigue (Bingham 2007, Akhtar et al. 2010)).

Responsibility or fault: Crash responsibility or who was at fault was frequently reported and typically determined as the person who violated traffic rules to establish legal liability (Noordzij 1976, Cross and Fisher 1977, Olkkonen 1993). On average, cyclists were at fault in 58.6% of fatality crashes (range: 37.3% (Olkkonen 1993) to 75% (Bajanowski et al. 1994)) with higher proportions reported in age-specific cyclist groups (children under 14 years: 100% (Dupont 1996); elderly: 83% (Olkkonen 1993)).

Error: Failure to see was the most commonly reported error, typically by drivers (Hoque 1990, Keigan et al. 2009, Valentine and Tillman 2010, Kelkka and Toivonen 2011, Lydall 2014) attributed to factors including: drivers' low expectancy of cyclists (Akhtar et al. 2010), driver cognitive load (Akhtar et al. 2010), driver inattention (daSilva et al. 2002, Akhtar et al. 2010), glare (ATSB 2006), cyclists in drivers' blind spot (McCarthy and Gilbert 1996, Akhtar et al. 2010), cyclists' lack of conspicuity (e.g. lack of bike lights)(Cycling Weekly 2008, Akhtar et al. 2010). Impairment due to substance misuse, including alcohol, by drivers also contribute to a failure to see (Rowe et al. 1995, ATSB 2006). Other errors included cyclist or driver misjudgement (Sjöegren et al. 1993, Bernhoft 1994, daSilva et al. 2002, Akhtar et al. 2010); loss of control (Got 1993, Ciferri 2005, Akhtar et al. 2010); unexpected behaviour (Oström et al. 1993, Spence et al. 1993, Komanoff and Smith 2000, Hutchinson and Lindsay 2010); visual obstruction (Klintschar et al. 2003, Nicaj et al. 2009, Hutchinson and Lindsay 2010); failed evasive manoeuvre (Cooke et al. 1993, Arenson 1997) and expectation (i.e. driver expected cyclist to yield)(Akhtar et al. 2010).

Violation: Behaviours that actively contributed to the crash event, as opposed to passive errors, were grouped as violations. Failure to yield was the most frequently identified violation by both cyclists (Got 1993, Sjöegren et al. 1993, Bernhoft 1994, US Department of Transportation 1994, McCarthy and Gilbert 1996, daSilva et al. 2002, Akhtar et al. 2010, Bíl et al. 2010, Kelkka and Toivonen 2011, Clarke 2014) and drivers (Bajanowski et al. 1994, Liu et al. 1995, McCarthy and Gilbert 1996, daSilva et al. 2002, Akhtar et al. 2010, Bíl et al. 2010, Hutchinson and Lindsay 2010, Clarke 2014). Cyclist violation was typically failure to stop at traffic signals (e.g. stop sign, red light)(Spence et al. 1993, Liu et al. 1995, Keigan et al. 2009, Valentine and Tillman 2010, Lydall 2014). Driver violation included overtaking cyclists too closely (Got 1993, Bernhoft 1994, McCarthy and Gilbert 1996, Clarke 2014), infringement of road rules, infringement at red lights, causing a hazard by opening a vehicle door (Liu et al. 1995, Arenson 1997, Komanoff and Smith 2000).

Habitual driving behaviour, including stretching the rules (e.g. previous speeding infringements)(Valentine and Tillman 2010), distraction (e.g. mobile phone use).

Other factors: Knowledge and experience, or lack thereof, was identified as contributing behavioural factors. Cyclists' lack of knowledge or indifference to road rules was identified (Cross and Fisher 1977, Akhtar et al. 2010, Kelkka and Toivonen 2011, Fraser et al. 2012) whereas lack of experience was identified for both cyclists (Cross and Fisher 1977, Liu et al. 1995, Webster 2006, Keigan et al. 2009, Fraser et al. 2012) and drivers (Mooar and Thomas-Lester 1997, Akhtar et al. 2010). Inadequate driving training was also identified (Akhtar et al. 2010).

Table 2. Details of publications on cyclist fatality crashes

Study	Type	Country	Method	Sample description			Safe System				
			Study design	Age	Sex	Total deaths	People	Speed	Vehicle	Road	Other
(Abt 1995)	D	France	N	A	M	9	+	+	-	+	-
(Ackery 2012)	W	USA	R, CC	All	All	711	+	-	+	-	-
(Akhtar et al. 2010)	G	Norway	R, CS	All	All	15	+	+	+	+	+
(Arenson 1997)	D	USA	N	A	F	1	+	-	+	-	-
(Attewell and Dowse 1992)	G	Australia	R, CS	All	All	86	+	+	+	+	-
(ATSB 2006)	G	Australia	R, CS	All	All	335	+	-	+	-	+
(Bajanowski et al. 1994)	W	Germany	R, CS	All	All	48	+	-	+	-	+
(Baker et al. 1993)	G	USA	R, CS	All	All	1984	+	-	-	-	-
(Bernhoft 1994)	W	Denmark	R, CS	A	All	89	+	+	-	-	-
(Bicycle Retailer & Industry News(2008)	D	USA	N	A	M	1	-	-	-	-	-
(Bíl et al. 2010)	W	Czech Republic	R, CS	All	All	968	+	+	-	+	-
(Bingham 2007)	D	UK	N	All	All	1	+	-	-	-	-
(Carpiet 2014)	D	USA	N	All	All	1	+	-	-	-	-
(Ciferri 2005)	D	Italy	N	A	M	1	+	-	-	-	-
(Clarke 2014)	G	USA	R, CS	A	All	633	+	-	-	-	-
(Cooke et al. 1993)	W	Australia	R, CS	All	All	64	+	-	-	-	-
(Cross and Fisher 1977)	G	USA	R, CS	All	All	166	+	+	+	+	+
(Cycling Weekly, 2008(2008)	D	UK	N	A	M	1	+	-	-	+	-
(Daily Mail, (2010)	D	UK	N	A	M	1	+	-	-	-	-
(daSilva et al. 2002)	G	USA	R, CS	All	All	760	+	+	+	+	+
(Dix and Bolesta 1988)	W	USA	R, CS	C	M	1	+	-	+	-	-
(Dupont 1996)	W	Denmark	R, CC	A	All	447	+	-	+	-	-
(Fife et al. 1983)	W	USA	R, CS	C	All	2	+	-	+	+	-
(Fraser et al. 2012)	W	Australia	R, CS	C	All	12	+	-	-	+	-
(Fredriksson et al. 2012)	W	Sweden	R, CS	All	All	48	+	-	+	-	-
(Gilbert and McCarthy 1994)	W	UK	R, CS	All	All	178	+	-	+	-	-
(Got)	G	France	R, CS	All	All	378	+	-	+	+	-
(Hawley et al. 1995)	W	USA	R, CS	All	All	36	+	-	-	-	-
(Hoque, 1990)	W	Australia	R, CS	All	All	122	+	-	+	+	-
(Hutchinson and Lindsay 2010)	G	Australia	R, CS	All	All	37	+	+	-	-	-
(IOM Today, (2008)	D	UK	N	C	M	1	+	-	+	-	-
(Keigan et al. 2009)	G	UK	R, CS	All	All	92	+	+	+	+	-
(Kelkka and Toivonen 2011)	G	Finland	R, CS	All	All	31	+	-	-	+	-
(Kim et al. 2007)	W	USA	R, CS	All	All	104	+	+	-	+	+
(Klintschar et al. 2003)	W	Austria	R, CStudy	C	M	1	+	-	-	-	-
(Komanoff and Smith 2000)	G	USA	R, CS	All	All	71	+	+	-	-	-
(Levy 2007)	D	UK	N	C	M	1	+	-	-	-	-
(Liu et al. 1995)	W	China	R, CS	All			+	+	-	+	+
(Lydall 2014)	D	UK	N	A	F	1	+	-	-	-	-
(Maki et al. 2003)	W	Japan	R, CS	A	-	9	+	-	+	-	-
(McCarthy and Gilbert 1996)	W	UK	R, CS	All	All	124	+	+	-	-	+
(Mooar and Thomas-Lester 1997)	D	USA	N	A	F	1	+	-	-	-	-
(Moore-Bridger 2009)	D	UK	N	A	F	1	+	-	+	-	-
(Moore-Bridger 2010)	D	UK	N	A	F	1	+	-	-	-	-
(Morgan 2014)	D	UK	N	A	M	1	+	-	-	+	-
(Morgan Andrei et al. 2010)	W	UK	R, CS	A	All	242	+	-	-	+	-
(New York Times,(2000)	D	USA	N	A	F	1	+	-	-	-	-
(Nicaj et al. 2009)	W	USA	R, CS	All	All	225	+	-	+	+	-
(Nie et al. 2015)	W	China	R, CS	A	M	67	-	+	+	-	-
(Nixon et al. 1987)	W	Australia	R, CS	C	All	46	+	-	-	-	-
(Noordzij 1976)	W	The Netherlands	R, CS	All	All	1382	-	-	+	+	+

Study	Type	Country	Method	Sample description			Safe System				
			Study design	Age	Sex	Total deaths	People	Speed	Vehicle	Road	Other
(Olkkonen 2002)	W	Finland	R, CS	All	All	23	+	-	-	-	-
(Olkkonen 1993)	W	Finland	R, CS	All	All	200	+	-	-	+	-
(Orsi et al. 2013)	W	Germany	R, CS	All	All	44	+	-	-	-	-
(Oström et al. 1993)	W	Sweden	R, CS	All	All	146	+	-	+	-	+
(Randhawa 2010)	D	UK	N	A	F	1	-	-	-	+	-
(Randhawa et al. 2013)	D	UK	N	A	All	2	-	-	-	-	-
(Rodgers 1995)	W	USA	R, CS	All	All	917	+	-	-	-	+
(Rowe et al. 1995)	W	Canada	R, CS	All	All	212	+	-	-	+	+
(Schimek 2014)	G	USA	R, CS	All	All	793	+	+	+	+	-
(Sentinella and Keigan 2005)	G	UK	R, CS	C	All	90	+	+	-	-	-
(Sjöegren et al. 1993)	W	USA	R, CS	A	All	55	+	-	-	+	+
(Spence et al. 1993)	W	Canada	R, CS	C	All	81	+	+	+	-	-
(Transafety Reporter, (1989)	G	USA	R, CStudy	C	M	1	-	-	-	+	-
(Valentine and Tillman 2010)	D	USA	N	A	All	10	+	-	-	-	+
(US Dept Transport'n, (1994)	D	USA	R, CS	All	All	814	+	+	-	+	-
(US Dept Transport'(2013)	D	USA	R, CS	All	All	677	+	-	-	+	-
(Venara et al. 2013)	W	France	R, CS	A	F	1	+	-	-	+	-
(Waller 1969)	G	UK	R, CS	All	All	109	-	+	-	+	+
(Watling et al. 2014)	D	UK	N	A	M	1	-	-	-	+	-
(Webster 2006)	G	UK	R, CS	All	All	49	+	-	+	+	-

General: + reported in article, -, not stated/specified Publication type: D, dirty; G, grey; W, white
Study design: R, Retrospective; N, newspaper study; CC, case-control; CS, case series; CStudy, Case study
Comparison group: -, no comparison group, DC, deceased cyclist; DORU, deceased other road user; NFC, nonfatal cyclist; NFORU, nonfatal other road user; FNF, fatal and nonfatal other road users
Age: All, all ages; A, adults only; C, children only Sex: All, both male and female; M, male; F, female

Table 3. Contributing factors in cyclist fatality crashes by Safe System approach

Safe people	Safe roads and roadsides	Safe vehicles	Safe speeds
Helmets^{+++}	**Intersections**$^{+}$	**Vehicle type**$^{+}$	**Excessive speed for conditions**$^{+}$
Substance misuse – alcohol, drugs^{+++}	**Poor light**$^{+}$	**No lights/reflectors**$^{+}$	**Excessive speed for skill**$^{+}$
At fault^{++}			
Fail to yield^{+}			
Failed to see^{+}			
Violation^{+}			
Overtook too closely^{+}			
Misjudgement^{+}			
Lost control, Position on the road, Fall, Impairment – age related, Clothing – no high visibility/reflective, Development child (physiological/ cognitive), Inexperience – cycling, Unexpected behaviour, Faulty – driving, Car door, Visual obstruction	No street lights, Location – metro/non-metro, Surface, Road furniture, Land use	Mechanical failure, Blindspot	High speed zones
Failed evasive manoeuvre, Distraction/inattention, Impairment – health related, Impairment – temporary, Knowledge of road rules, Clothing – footwear, Fatigue, Thrill seeking/risk taking, Bike path – incorrect use, Inexperience – driving, Race related, Expectation, Driver training (inadequate)	*No bike lane, Roadworks, Traffic volume*	*Vehicle design, Side protrusion, Bike – load, luggage*	

Number of publications (range) that identified factor: italics <3, plain text 3-10; + 11-20; ++21-30; +++: >30

3.3.2 Safe System factors – Safe Roads and Roadsides

Ten factors were identified in the safe road and roadsides category. Intersections were frequently identified as the location of urban cyclist fatality crashes (Cross and Fisher 1977, Olkkonen 1993, Sjöegren et al. 1993), particularly when heavy vehicles and cyclists shared the space or the driver sight line obstruction (Keigan et al. 2009). Cyclist fatality crashes on rural roads were more likely to occur at non-intersections where speed, obstructed sight lines or road curvature were factors and provision of bike lanes or road widening were considered cost prohibitive (Cross and Fisher 1977, Fraser et al. 2012).

Lighting conditions were a key contributing factor, with the risk of fatal outcome several times greater at dawn/dusk and night time compared to in daylight (Waller 1969, Noordzij 1976, Cross and Fisher 1977, Attewell and Dowse 1992, Bíl et al. 2010). During low light times drivers were more likely to fail to see cyclists (Rowe et al. 1995, Schimek 2014) particularly for night time crashes that occurred on rural roads that had no street lighting (Fife et al. 1983) and high speed limit (e.g. 100 kph)(Noordzij 1976, Hoque 1990).

Poor road surface, damaged or broken surfaces, were contributive in cyclist-fall crashes (Venara et al. 2013). Also identified were: roadworks/temporary road changes need to consider how cyclists can safely navigate the altered space (Transafety Reporter 1989) and on-road structures (Morgan 2014) as well as roadsides, in particular poor sight lines obstructed by road design, parked cars or roadside vegetation (Cross and Fisher 1977, daSilva et al. 2002, Akhtar et al. 2010). Unintended consequences of roadside furniture were also a factor (e.g. cyclist crushed against fencing at a roundabout) (Webster 2006, Moore-Bridger 2010).

Off-road cyclist fatality crashes were largely absent from the examined publications. We were unable to determine if this absence was because few fatalities occurred off-road or because data used in the publications was limited to on-road crashes.

3.3.3 Safe System factors – Safe Vehicles

The majority of all cyclist fatality crashes involved a collision with a motor vehicle. The main focus of motor vehicle safety was on vehicle occupants, with little attention given to the safety of non-occupants including cyclists, motorcyclists and pedestrians(Ackery 2012).

Large vehicles were involved in a disproportionate number of cyclist fatality crashes(Morgan Andrei et al. 2010, Kelkka and Toivonen 2011, Ackery 2012). Over half of the publications reported heavy vehicle crash involvement (53.4%) and these crashes were more likely to result in a fatality compared to crashes with other vehicle types (Kim et al. 2007, Kelkka and Toivonen 2011). In relation to their traffic volume, heavy vehicles were estimated to cause up to 30 times as many cyclist deaths as cars and 5 times as many as buses (Gilbert and McCarthy 1994, Morgan Andrei et al. 2010). Crash contributing factors included larger physical dimensions of the vehicle (Moore-Bridger 2009, Akhtar et al. 2010, Moore-Bridger 2010, Ackery 2012) and the unguarded wheels (Cross and Fisher 1977, Hutchinson and Lindsay 2010, Lydall 2014). In several cases, cyclists were dragged as the driver was unaware they had hit the cyclist (Dix and Bolesta 1988, Klintschar et al. 2003, Akhtar et al. 2010, Randhawa et al. 2013). Side mirrors had also struck the cyclist as the vehicle passed (Cross and Fisher 1977, Fife et al. 1983, Akhtar et al. 2010, Hutchinson and Lindsay 2010).

A bicycle with no or inadequate lights was identified in night time crashes, particularly in areas with no street lighting (Noordzij 1976, Cross and Fisher 1977, Fife et al. 1983, Hoque 1990, Olkkonen 1993, Fraser et al. 2012, Schimek 2014). One study reported two thirds (67%) of cyclist fatality crashes involved a bike with no lights (Attewell and Dowse 1992).

3.3.4 Safe System factors - Speed

Speed was a major contributing factor in cyclist fatality crashes (Bíl et al. 2010). Three key factors were identified in relation to speed: excessive speed for conditions, excessive speed for skill level (typically in relation to cyclists) and posted speed limit being too high. Kim et al (2007) reported when estimated vehicle impact speed is greater than 60km/h the probability of a cyclist fatal injury increased by more than 11-fold.

Excessive speed was identified for both cyclists and drivers. Cyclist excessive speed related to a range of crash events including losing control in a race (Abt 1995), cycling downhill (Attewell and Dowse 1992, Abt 1995, Akhtar et al. 2010) collisions with stationary objects/vehicles (Hutchinson and Lindsay 2010), and riding at speed through an intersection (Sentinella and Keigan 2005). Driver excessive speed was typically related to the posted speed limit (Bernhoft 1994, Keigan et al. 2009, Bíl et al. 2010).

4. Discussion

This systematic review examined 71 publications that reported contributing factors to fatal cyclist crashes. These publications were conducted internationally over a period exceeding 45 years and 52 contributing factors were identified within the Safe System approach. Over half of the contributing factors related to behaviours of the cyclist and/or counterpart. Most frequent were absence of helmets and impairment from substances. There was a general consensus helmet non-use increased the risk of a fatal outcome. Similarly, there was a consensus that impairment, particularly alcohol intoxication by the counterpart driver, was a contributing factor. Other behavioural factors shown to be contributory included: poor conspicuity of the cyclist and/or the bike; other impairment of the cyclist or counterpart driver due to their age, physical health or fatigue; and cyclist and/or counterpart violations or errors.

A further ten contributing factors were identified related to roads and road sides. In urban environments, fatal cyclist crashes frequently occurred at intersection, particularly when co-occurring contributing factors were present such as road design, road user behaviour or the counterpart was a heavy vehicle. Cyclist conspicuity was identified as a contributing factor at low light times or locations. Other contributing factors included poor road surface, road curvature or road side objects obstructing the driver's vision of the cyclist.

Eight contributing factors identified were related to vehicles. Heavy vehicles were reported as being involved in crashes resulting in death given not only their mass but also the presence of the visual obstruction created by the height of the vehicle from the road. With respect to the bike, poor conspicuity from the absence of lights and reflectors was cited in many of the publications as a contributing factor. Speed in excess of the posted limit, the prevailing conditions and/or skill level was also shown to be an important contributing factor for both the cyclist and counterpart driver. Speed exceeding 60km/hour was posited in one study as an important threshold for injury outcomes for cyclists. Three additional factors were identified as contributory outside of the Safe System approach (lighting, weather conditions and traffic volume).

4.1 Implications

The Safe System framework has advanced the approach to road safety by considering the risks and points of intervention across the transportation system. Overemphasis on road user behaviour immediately prior to a crash often failed to identify the broader systemic issues. Further, scientific research evidence over the last two decades has influenced the introduction of laws to address two major behavioural factors: absence of helmets and impairment from substances.

Many factors that contribute to cyclist fatality crashes are identified in this study, however in Australia, most of these factors are missing from the public policy approach to improving cyclist safety. The rationale for these omissions is not clear. It is possible that a population approach has been taken to road safety, that is action to achieve the maximum benefit for the greatest proportion of the population and as cyclists are too few, they have been excluded from mainstream policies. However, the benefit of cycling and need for a safe cycling environment extends beyond road safety. Action to achieve safer cycling needs to be considered in the broader context of the benefits gained at an individual and societal level from improved health, vehicle congestion, environmental, economic and social mobility perspectives. Integration of cyclist safety into the current policy framework, including road safety, is needed to achieve meaningful improvements in the cycling environment in countries with low levels of cycling participation including Australia.

5. Conclusions

This study provides the first systematic review of the English language literature on factors that contribute to cyclist fatality crashes. Findings from this study can be used to understand cyclist fatality crashes from a Safe System perspective and inform public policy to improve cyclist safety. While the major factors that contribute to many road crashes, alcohol/drug misuse, speed, distraction and fatigue are also prevalent in cyclist fatality crashes, other cyclist-specific factors need to be specifically targeted to improve cyclist safety. The many factors that contribute to cyclist fatality crashes have been considered, however the review has focussed only on fatality crashes. It is likely the factors that contribute to nonfatal crashes differ from those identified here. Further research is required to identify the contributing factors in nonfatal cyclist crashes.

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