Vulnerable Road User Groups: A Review of Younger Drivers, Motorcyclists and Older Drivers

Abstract

Scientific efforts to understand and reduce the occurrence of road crashes continue to expand, particularly in the areas of vulnerable road user groups. Three groups that are receiving increasing attention within the literature are younger drivers, motorcyclists and older drivers. These three groups are at an elevated risk of being in a crash or seriously injured, and research continues to focus on the origins of this risk as well as the development of appropriate countermeasures to improve driving outcomes for these cohorts. However, it currently remains unclear what factors produce the largest contribution to crash risk or what countermeasures are likely to produce the greatest long term positive effects on road safety. This paper reviews research that has focused on the personal and environmental factors that increase crash risk for these groups as well as considers direction for future research in the respective areas. A major theme to emerge from this review is that while there is a plethora of individual and situational factors that influence the likelihood of crashes, these factors often combine in an additive manner to exacerbate the risk of both injury and fatality. Additionally, there are a number of risk factors that are pertinent for all three road user groups, particularly age and the level of driving experience. As a result, targeted interventions that address these factors are likely to maximise the flow-on benefits to a wider range of road users. Finally, there is a need for further research that aims to bridge the research-to-practice gap, in order to develop appropriate pathways to ensure that evidenced-based research is directly transferred to effective policies that improve safety outcomes.

Key words: younger drivers, motorcyclists, older drivers.

INTRODUCTION

Younger drivers, motorcyclists and older drivers are three groups that are receiving increasing attention within the literature in regards to both understanding their increased risk of being involved in a crash as well as developing effective countermeasures to reduce such risk. As noted above, it currently remains unclear what factors produce the largest contribution to crash risk for these groups, and as a result, the following provides a review of such personal and environmental factors as well as provides direction for future research. While it is noted that a number of other vulnerable road user groups exist (e.g., pedestrians, cyclists, etc), for reasons of parsimony, the following review focuses on the three mentioned groups.

Younger Drivers

Of all the vulnerable road user groups, it may be argued that younger drivers are a particular "at risk" group. From the moment younger drivers negotiate the road with an intermediate (Provisional) driver's licence, they are at an increased risk of being injured or killed in a road crash. This trend is not unique to Queensland or Australia; rather this major public health problem is a trend that is repeated around the motorised world. Persistent characteristics apparent in young driver crashes including driver impairment, inattention, their personal states, vehicle type, and interactions among these risk factors will be reviewed below.

Crash Rates among Younger Drivers

While age and experience remain confounded in investigations of young driver behaviour and risk factors (Clarke, Ward, Bartle, & Truman, 2006), it has been noted that inexperience is a major contributor (McCartt et al. 2009). Taken together, younger age at full

licensure is associated with greater crash and offence rates. Statistically, being involved in a crash or offence decreases for the young novice driver at approximately 8% and 6% respectively per year of licensure (Waller, Elliott, Shope, Raghunathan, & Little, 2001). Additionally, young novice drivers experience 10 times greater crash rates per kilometre travelled than more experienced drivers, with their risk reducing significantly after the first 2 years of driving (McKnight & McKnight, 2003). Research has also shown that novice drivers are more likely to be at-fault in crashes (Braitman, Kirley, McCartt, & Chaudhary, 2008). It is also noteworthy that unlicensed driving appears to be a common behaviour for young drivers. For example, nearly three quarters of a sample of Learner drivers in Victoria reported they had driven a car before they had a valid learner licence, although it is noted this sample was quite small (Harrison, 2004).

In regards to gender, young male novice drivers consistently have higher crash fatality rates than their female counterparts. To illustrate, of the 200 drivers aged 17-25 years killed in Australia in 2007, 82% were male, and of the 97 fatally-injured similarly-aged passengers, 65% were male. Young male drivers experienced 12.1 deaths per 100,000 population, four times the rate of females in this age group (DITRDLG, 2008). These rates continue to be more than double that of drivers twice their age (ATSB, 2004a), a trend repeated across the globe (Williams, 2003).

Factors Contributing to Risk

Driver Impairment

Impaired driving is frequently found among young novice drivers involved in crashes (Asbridge, Poulin, & Donato, 2005), and is particularly problematic as the young driver is inexperienced in both the effects of alcohol and the demands of the driving task (Peck, Gebers, Voas, & Romano, 2008). Fatalities among young drivers are more likely to be

alcohol-related than those among older drivers (Queensland Transport, 2005). Young drivers also commonly report driving after drinking, with one in 5 males and 1 in 10 females in Victoria driving after drinking alcohol (Vassallo et al., 2007). Moreover, if the young driver crashes after drinking, they are more likely to drink, drive, and crash again (Ferrante, Rosman, & Marom, 2001); and alarmingly, young persons report frequently travelling as the passenger of a drinking driver (e.g., Muilenberg, Johnson, Usdan, Annang, & Clayton, 2007).

Driving whilst impaired by illicit drugs is also problematic for young drivers (Fergusson, Horwood, & Boden, 2008). Nearly one in seven Queensland motorists (Furler, 2007) and one in ten young drivers in Victoria, again more males than females (Vassallo et al., 2007), admit to driving after using illicit drugs. In Queensland during the five years to 31 December 2010, 23.7% of young adult drivers involved in fatal crashes were drink driving, and 26.4% of drivers were affected by drugs and/or alcohol (DTMR, 2011c). Furthermore, half of surveyed American teens reported they had seen their friends drive whilst under the influence of alcohol, and 2 in 5 had seen their friends drive whilst under the influence of marijuana (The Children's Hospital of Philadelphia, 2008). These statistics are particularly concerning, as a Danish study reported a 25 times greater risk of harm from driving after using illicit drugs either alone or in combination, increasing to 35 times greater if the driver had also consumed alcohol (Twisk & Stacey, 2007). Crash statistics detailing the rates of young novice driver impairment due to alcohol or illicit drugs do not explain *what* and *who* influenced the young adult to drive whilst in that impaired condition.

Inattention

Inattention to the driving task is also commonly found among young drivers, who are more easily distracted from the driving task (Neyens & Boyle, 2007). An American study reported that police had concluded that inattention was involved in 32% of fatal crashes

involving a 16 year-old driver (Williams, Preusser, & Ferguson, 1998, cited in Williams, Ferguson, & McCartt, 2007). Young drivers are also more likely to be at fault in crashes through inattention (Zhang, Fraser, Lindsay, Clarke, & Mao, 1998) as they are less experienced in the multitude of cognitive, information processing, and behavioural demands of the driving task (Evans, 1991; Gregersen, Berg, Engstrom, Nolen, Nyberg, & Rimmo, 2000). Verbal and physical interactions with young passengers can also distract the young driver from the driving task (Gugerty, Rakauskas, & Brooks, 2004), also highlighting the social influence of passengers. Disturbingly, a recent American study reported that the passengers of high school students frequently distracted the driver, through such actions as hitting or punching the driver, grabbing the steering wheel and emergency brake, and throwing things at the driver (Heck & Carlos, 2008). The age of passengers and their relationship to the young driver clearly influences the likelihood of young drivers crashing (Evans, 1991), and adults aged over 25 years are absent in more than 80% of young driver crashes (Miller, Spicer, & Lestina, 1998). Young drivers may be temporarily distracted by factors that are beyond their control, such as roadside features, or voluntary factors such as mobile telephones (Traffic Injury Research Foundation, 2011). Using in-car technology such as radios, compact disc players, navigation devices, and mobile telephones has been found to both distract the inexperienced young driver from the driving task (Ferguson, 2003).

Personal State

Young drivers also place themselves at risk by not utilising the safety features of the vehicle they are driving, particularly seat belts. Young drivers comprised 26% of all unrestrained fatalities in the five-year period to 31 December 2010 in Queensland (DTMR, 2001). Young passenger seat belt use reflects that of their young driver (Begg & Langley, 2000), with seat belts least likely to be used when multiple young passengers are present at night (McCartt & Northrup, 2004). Male and female Victorian drivers aged 19-20 years

report they do not wear a seat belt at all in more than 11% and 6% of their journeys respectively, and wear a seatbelt for only part of the trip 15% and 9% of the time respectively (Vassallo et al., 2007). The psychosocial influences upon this risky behaviour are yet to be determined. Young drivers are also developmentally-prone to emotional driving, and emotions such as anger and excitement are not only related to the driver's personality, but are frequently experienced in response to events during driving (Mesken, Hagenzieker, Rothengatter, & de Ward, 2007). Three-quarters of surveyed American youth reported they had seen teens driving whilst experiencing strong negative and positive emotions such as anger or excitement, with over half reporting they had seen instances of 'road rage' (The Children's Hospital of Philadelphia, 2008). Again, the psychosocial influences upon this risky behaviour remain to be identified.

Vehicle Type

Vehicle characteristics that have been found to be associated with young driver crash and fatality rates include the size and age of the vehicle, the type of crash and the number of vehicles in the crash. Young drivers are more likely to travel in smaller, older cars, as they are cheaper to buy, however they do not offer the crash avoidance and the crash protection measures incorporated in newer, larger cars (Ferguson, 2003). Smaller older cars are involved in nearly five times as many young driver crashes as larger cars (Williams & Wells, 1995), and a five year increase in the model year of the car driven corresponds to a 5% increase in the odds the young driver will be fatally injured (Bedard, Guyatt, Stones, & Hirdes, 2002).

Interactions

Finally, the above factors have been proposed to interact and thus further increase younger drivers' vulnerability to crash involvement. For example, the gender of young passengers and young drivers also interacts, with male drivers accounting for 84% of male

and 59% of female young passenger deaths (Williams & Wells, 1995). Male teen drivers leaving a high school in America were observed to tailgate and speed when carrying a young male passenger, and conversely this behaviour was less likely if the passengers were female (Simons-Morton, Lerner, & Singer, 2005). A New Zealand study concluded that the number of passengers was the most significant predictor of young driver crashes after controlling for gender, BAC, mileage, fatigue, and time of day. Control vehicles detained at crash sites revealed young passengers increased the likelihood of a crash in the order of five times (Lam, Norton, Woodward, Connor, & Ameratunga, 2003). Journey characteristics that have been found to be associated with young driver crashes and fatalities include speeding behaviour, and the time and day and day of week of the journey. Driving at night is more risky for drivers of all ages, for example due to the reduced visibility of the road environment and its surroundings to the driver (Williams et al., 2007), but driving in darkness appears particularly risky for young drivers. Nationally in 2007, 60% of drivers aged less than 26 years were killed between 6:00 p.m. and 6:00 a.m., compared to 40% of drivers over 26 years (DITRDLG, 2008).

Motorcyclists

Motorcyclists are among the most vulnerable road user groups internationally. It has been estimated that there are approximately 313 million motorcycles in the world, and 77% of them can be found in Asia (Rogers, 2008). Powered two wheel vehicles also come in diverse forms and are used for a range of purposes in different parts of the world (Haworth, 2012), which naturally impacts upon crash risk for motorcyclists of different nations. Powered two wheel vehicles are most often considered to relate to mopeds, scooters and motorcycles, although this review will focus predominantly on motorcycles. There are a number of advantages of using motorcycles, including fuel economy, traffic congestion advantages and increased parking opportunities that this form of transport offers. Not

surprisingly, the number of motorcycle riders continues to increase both in developed and developing countries. However, there are a number of challenges that relate to motorcycle usage, in particular safety (Haworth, 2012) which will be reviewed below.

Crash Rates among Motorcyclists

Motorcycle riding is more likely to result in injury than car travel, and the resulting injuries are also likely to be more severe (DIT, 2010). The fatality and injury rates are worse than for car occupants, regardless of whether the denominator is registered vehicles, licensed riders or distance ridded (Haworth, 2012). There appear to be two main groups who are most at risk. Younger riders aged 16-24 years and older riders aged 25 -54, and this latter group are the fastest growing cohort among serious crashes (Haworth, Mulvihill & Clark, 2006). Interestingly in regards to the latter group, research has shown that older drivers who have returned to riding after a long absence have a higher crash risk per distance travelled than older drivers who have continued to drive and remain licensed (Haworth & Mulvihill, 2003). However, these figures are influenced by registration rates, as motorcycles that become involved in crashes may not be registered, and not all registered motorcycles are ridden on the road at all times (Haworth et al., 2006).

Factors Contributing to Risk

Vulnerability to Injury

Similar to younger drivers' fatality risk, there are a number of factors that contribute to motorcyclists' crash risk. One of the primary contributors to motorcyclists' injuries is the reduced level of physical protection against other vehicles, as well as the ground and roadside objects (Royal Society Prevention of Accidents, 2001; Haworth, Smith, Brumen & Pronk, 1997). As a result, injuries are usually more severe. An earlier study estimated that

approximately 80% of motorcycle crashes result in injury or death, compared with only 20% for automobiles (Motorcycle Safety Foundation, 1999). Motorcycle collisions with guardrails have been shown to have a dramatically higher fatality risk than passenger vehicle collisions with guardrails (Gabler, 2007).

Age and Inexperience

Similar to above, both age and inexperience have been proposed to be major contributors to motorcycle riders' increased presence in injury and fatality statistics. Research continues to demonstrate that new riders have more crashes per year than experienced riders, although it should also be noted that younger riders (both new and fully licensed) have more crashes per year than older drivers (Haworth et al., 2006). This suggests that both age as well as experience are important contributory factors to motorcycle crashes. However, it remains less clear as to what extent exposure contributes to crash risk, although researchers have suggested that these three factors are likely to be inter-correlated (Haworth et al., 2006).

Poor Conspicuity of Motorcycles

A further factor that has been proposed to influence the increased risk for motorcycle crashes is when motor vehicle drivers fail to observe motorcyclists in their path. This problem is particularly evident at intersections, as vehicles emerge and cross the path of the motorcyclist who may have priority in regards to right of way (RoSPA, 2001). Additionally, motorcycle riders are often injured when passenger vehicles change lanes into the path of motorcyclists and do not see them. It has been proposed that failing to detect or recognise motorcycles is the most common cause of motorcycle collisions (Haworth et al., 2006). This may be because motorcycles are smaller than other types of motor vehicles, and thus it is harder from drivers to see them (RoSPA, 2001).

Instability, Environmental Hazards and Risk Taking

There are a range of other factors that may increase the risk of motorcyclists to be involved in a crash. Although this assessment of risk is complicated as motorcycle fatalities often involve multiple impacts e.g., ground and road barrier (Daniello & Gabler, 2011). Firstly, it is noted that two wheeled vehicles are less stable than four wheel vehicles (Haworth et al., 2006). Following on from this, it has been suggested that braking effectively is more difficult on motorcycles due to the separate nature of the front and rear braking systems (Motorcycle Safety Foundation, 2005). The road surface and other environmental hazards are important factors that also increase crash risk for motorcyclists. An earlier study by Harworth (1999) estimated that the road surface contributed to approximately 15% of crashes. Road surface factors vary considerably and can include unclean roads or lose material, poor road condition, poor road markings and horizontal curvature of the road (Haworth et al., 2006). Other fixed environmental objects also remain a considerable concern for motorcyclists. For example, a recent study by Daniello & Gabler (2011) that examined the fatality risk of motorcyclists either hitting the ground or road side objects found that fixed objects (e.g., guard rails) are more harmful than the ground. The study examined 3600 fatal motorcycle crashes reported in the Fatality Analysis Reporting System (FARS) between 2004 and 2008 and concluded that hitting a guard rail was 7 times more likely to result in a fatality than hitting the ground, and collisions with trees were 15 times more likely to result in a fatality than hitting the ground. Not surprisingly, narrow objects such as trees have a greater fatality risk compared to guardrails (Tung et al., 2008).

Risk taking has also been proposed as another area of concern for motorcyclists that increases the likelihood of crashes. For example, motorcycle riding offers both vulnerability and excitement, and it is not surprising that this endeavour attracts individuals who are prone to take risks (Haworth et al., 2006). While there has been limited research that has clearly

quantified the relationship between risk taking and crash outcomes, researchers have suggested that risk taking is likely to be reflected in the increased crash risk for recreational riding as compared to purely riding for transport reasons (Haworth et al., 1997). More recent research has demonstrated that younger male riders are more likely to disobey traffic signs and regulations and have a higher tendency towards negligence of the potential risks of riding (Chang & Yeh, 2007). Other research has found that younger drivers have a stronger propensity for risky behaviours (Lin et al., 2003) and are more willing to break the law and violate the rules of safe riding behaviours (Rutter & Quine, 1996).

Older Drivers

Another vulnerable driving group are older drivers, and this group represent the largest growing cohort of the Australian driving population. According to predictions by the Australian Institute of Health and Welfare (2001), the population of Australians aged over 65 years of age is anticipated to double from 12.5% in 2000 to 25% in 2021. This follows the global trend of aging population, especially amongst developed countries such as the United States and Europe. Due to improvement in medical care, older drivers are also keeping their licences longer (Lyman, Ferguson, Braver, & Williams, 2002). Resulting from a range of factors, such as the rapid rise of the older driver cohort, older drivers' high crash rate per distance driven has become a challenging social and health problem for many developed countries (Hakamies-Bomqvist & Peters, 2000).

Crash Rates and Crash Severity Among Older Drivers

Literature continues to identify the rapid increase in both prevalence and severity of crash risk among older drivers (Cerelli, 1995; McGwin & Brown, 1999; Holland, 2002). Motor vehicle crash rates adjusted for distance travelled reveal that older drivers are more susceptible to road crashes, with an exponential increase after the age of 75 (Guerrier,

Manivannan & Nair, 1999; Preusser, Williams, Ferguson, Ulmer, & Weistein, 1998; Retchin & Anapolle, 1993). For instance, after adjusting for driving exposure, Cerelli (1995) found that crash rate increase rapidly after age 70, and that drivers aged over 75 recorded a 37% higher crash rate than other drivers. Driver fatality rates reveal a similar pattern of overrepresentation of older drivers (e.g. Preusser et al., 1998, Retchin & Anapolle, 1993).

As older drivers typically drive less distance per year than drivers of other age groups, debate exists whether the increased crash risk reported among older drivers is a result of the low mileage bias (i.e. the lower annual mileage driven, the higher the per-distance crash rate) (Langford, Methorst & Hakamies-Bomqvist, 2006). Because older drivers generally drive less distance per year, this association has been used to account for their overrepresentation in crashes (Langford & Koppel, 2008). Nonetheless, the increased fragility of older drivers places them at a disproportionate risk of sustaining serious injury or death as a result of being involved in a crash (e.g. Li, Braver, & Chen, 2003; McGwin et al., 2000; Viano et al., 1990).

Factors Contributing to Risk

Cognitive Factors

The effects of aging on the cognitive ability of road users have been widely investigated. Cognitive-aging studies consistently report older drivers demonstrate impairment in age related declines in cognitive capacity, particularly in executive functions and visual attention (Bryan & Luszcz, 2000). Recent neuro-imaging studies have offered support to the area, showing age-related changes in the prefrontal cortex (Raz, Gunning-Dixon, Williamson, & Acker, 2002). The neuropsychological evidence in cortical shrinkage of older adults is also consistent with behavioural studies in the area of traffic psychology that demonstrate age-related declines in various driving-related tasks (McGwin, Chapman & Owsley, 2000; Owsley et al., 1998; Owsley & McGwin, 1999; Wood & Mallon, 2001). Not

surprisingly, given the documented difficulties experienced by older adults in tasks that demand attentional control, the types of crashes in which older drivers are involved often occur in complex traffic environments, such as intersections and highways (McGwin & Brown, 1999).

In addition to executive functions, a decline in visual attention has been reported to be a significant predictor of driving performance. In particular, performance on the Useful Field Of View (UFOV) has been documented to yield moderately large sized associations with crashes and on-road test (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; De Rasedt & Ponjaert-Kristoffersen, 2000; Owsley et al., 1999 and Roenker et al., 2003). UFOV is used to assess visual attention. It involves identifying targets in the periphery with and without distractors while completing a central discrimination task. In two prospective case-control studies, poor performance on the UFOV was correlated with 87% to 107% increased in crash risk (Owsley, Ball et al. 1998 and Sims et al., 2000). A recent meta-analytic study by Clay et al. (2005) highlighted the importance of visual attention in driving performance, reporting a large effect size (Cohen's d = .945) for the relationship between performance on the UFOV test and a range of negative driving outcomes.

Vision

The effects of visual impairments and driving performance are another area in the older driver safety literature that has received much empirical attention. Driving requires the ability to process complex visual scenes with potential hazards in both the central and peripheral visual field. Thus, changes in visual ability have vital implications for safe driving. Of particular relevance is the commonly reported age-related change in visual function, due to both the normal aging process and the increased prevalence of eye disease (Attebo, Mitchell & Smith, 1996). Normal aging is related with increased yellowing and cloudiness of

the crystalline lens, alterations in the integrity of the macular pigment and neural pathways as well as a decrease in pupil size (Anstey, Wood, Lord & Walker, 2005). These changes lead to increase in glare sensitivity, reductions in visual acuity and contrasts sensitivity typically seen in older adults (Haegerstrom-Portnoy, Schneck & Brabyn, 1999). Normal age-related changes aside, older populations also exhibit dramatic increased prevalence in ocular disease such as cataract, glaucoma and age-related maculopathy (Klein et al., 1995).

Intuitively, given that vision is a main sensory input of driving, age-related visual impairment has been perceived by many to be an important risk factor for driving performance (Unsworth et al., 2007). Some studies have reported visual impairments to be significantly related to crashes and traffic violations among older drivers (e.g. Richardson & Marottoli, 2003; Hoffman, McDowd, Atchley, & Dubinsky, 2005; Bedard et al., 2006). However, associations between visual acuity and driving outcome measures, if statistically significant, are generally weak in effect size. A recent literature review by Anstey et al. (2005) concluded that such inconsistent results suggest that visual ability in isolation are not strong predictors of driving ability.

Fragility

Due to older drivers' increased fragility, especially in terms of reductions in bone strength and fracture tolerance, older drivers are also significantly more likely to sustain serious injury or death as a result of crash (e.g. Viano et al., 1990; Evans, 1991; Dejeammes and Ramet, 1996; Mackay, 1998; McGwin, Sims, Pulley, & Roseman, 2000; Padmanaban, 2001). Compared to drivers aged 30-59, those who are 70-74 years of age were twice as likely to die as a result of a crash (Li, Braver, & Chen, 2003). Further, drivers aged 80 years and over were about five times more likely than their 30-59 year old counterparts to die from crashes. Meuleners et al. (2006) offered a similar pattern in morbidity, reporting that older

drivers aged over 70 were found more than twice as likely to sustain serious injury following a crash compared to 30-59 year older drivers. For instance, Lyman et al. (2002) observed that chest injuries and fractures are significantly more common among older vehicle occupants. Increased fragility may also exacerbate effects of the various cognitive, sensory and physical impairments have on driving performance (Li et al., 2003).

Medical conditions and medications

Several studies have provided emerging evidence that medical conditions and medications may place older drivers at risk of unsafe driving and sustaining more serious injury or mortality when involved in crashes (McGwin et al., 2000; Li, Braver & Chen, 2003). However, compared to literature on the cognitive and/or visual factors, literature on the relationship between medical conditions and driving performance and older drivers' safety remains scarce, and relatively inconsistent.

Using a population-based case-control design, McGwin, Sims, Pulley and Roseman (2000) sampled 901 older drivers from Alabama in the US, and found that those with heart disease or stroke and arthritis were significantly more likely to be involved in at-fault motor vehicle crashes. This is consistent with the findings of Margolis and colleagues (2002), which reported after adjustment for age and driving frequency, motor vehicle crashes were significantly associated with a greater orthostatic blood pressure drop, foot reaction time and a fall in the previous year. Previous studies have also found that use of nonsteroidal anti-inflammatory drugs, anticoagulants and psychoactive medications, such as Benzodiazepine, were also associated with a significant increase in crash risk (Leveille et al., 1994 and Ray, Thapa & Shorr, 1993).

While postural stability (Treffner, Barrett, & Petersen, 2002) and neck rotation in both directions (Maratolli et al., 1998) has been reported to correlate with poor driving

performance, studies failed to find a significant relationship between driving performance and grip strength, shoulder abduction and trunk rotation (Maratolli et al., 1998; Sims et al., 1998, 2000). Although it is intuitive to expect decreases in physical functions as a result of "normal" aging process or age-related illness (e.g. arthritis) would reduce older adults' capacity to drive, there is little evidence at this stage to support this view.

The Interaction Between Physical, Sensory and Cognitive Factors

It is important to acknowledge that the above reviewed cognitive, sensory and physical factors are interrelated in the driving process, and also likely to bi-directionally influence other factors not reviewed above. For instance, reduced neck rotation may prevent the ability of the driver to turn and scan relevant stimuli in the peripheral visual field. However, competent driving also requires efficient decision-making abilities, using executive function to integrate and evaluate available sensory information prior to deciding on and executing a behavioural response. While information may be limited due to reduced sensory function, intact executive function may allow the driver extra time to obtain sensory information, buffering the effects of sensory impairments. Another example of the potentially moderating effect of the cognitive functions is the interaction between hearing loss and road conditions reported by Hickson et al. (2010), which demonstrate the deleterious effect of moderate to severe hearing impairments on driving performance may not be evident unless the driver engages in traffic conditions that demand a high cognitive load. Taken together, future research that investigates the effects of various functional declines on older drivers' driving capacity need to consider multiple declines simultaneously (i.e. more than direct correlations) to accurately determine their impact on older drivers' crash risk.

Future Research

Given younger and older drivers as well as motorcycle riders appear at an increased risk of crash involvement (and sustaining life threatening injuries) there is a considerable need for future research to develop effective countermeasures to reduce these groups' risk while driving.

In regards to younger drivers, their significantly higher crash and fatality rates have seen the development and implementation of a variety of countermeasures, such as media campaigns, driver education and training, in-car technologies, and graduated driver licensing (GDL) programs. Whilst driver education, training and media campaigns are consistently found to be popular with the driving public, they have not been found to reduce the crash and fatality rates of young drivers (Elliott, 1992; Lewis, Watson, & White, 2009). Promising results are also evident for GDL programs, which vary widely in structure, privileges and restrictions around the world (Hartos, Simons-Morton, Beck, & Leaf, 2005; Masten & Hagge, 2004).

What is *not* well understood by road safety researchers and policy makers alike is what and how a range of psychosocial variables influence the risky behaviour of young drivers. This includes not only the influence of the personal characteristics of the younger driver (e.g., the influence of depression, anxiety, and sensation seeking propensity, Scott-Parker, Watson, King, & Hyde, online first), but also the influence of their parents, who are models of driving attitudes and behaviours and who are also pivotal in the learning-to-drive process (Simons-Morton, Ouimet, & Catalano, 2008). Friends have also been found to influence the behaviour of younger drivers via both explicit and implicit means (Regan & Mitsopoulos, 2001). An understanding of the nature, extent and mechanisms of these psychosocial influences upon the risky behaviours of young drivers will inform countermeasure development, potentially including the enhancement and increased efficacy of existing countermeasures such as GDL.

Therefore, further improvements in young driver road safety will require a more extensive understanding of the complex and multiple influences that affect young driver risky behaviour. In particular, crash, offence and insurance data limits the understanding of the nature and extent of crash contributors to what can be objectively measured (such as blood alcohol concentration) or reported by individuals who survive or witness the crash (such as in-vehicle interactions with the driver immediately prior to the crash). This limited insight may also be impacted upon by the driver's and/or passenger's recall accuracy, attempts to evade punishment, or vested interests such as to ensure that the crash will be financially-covered by the insurance provider. Most importantly, as noted earlier a variety of factors frequently interact and place the younger driver at greater risk, therefore examining the influence of contributors in isolation cannot capture the full breadth and mechanism of their influence.

Quantitative techniques such as self-report surveys, qualitative techniques including focus groups and interviews, and more recently naturalistic observations via in-car recordings have been able to provide unique insight into the experiences and behaviours of novice drivers. Self-report surveys can provide insight into behaviours that may not be readily measurable via other methodologies, for example driving whilst fatigued (Scott-Parker, Watson, & King, 2010), and insight into personal risk, such as anxiety and depression (Scott-Parker, Watson, King, & Hyde, 2011). Further research utilising surveys can also allow an evaluation of the effectiveness of existing countermeasures, including the younger driver's compliance with GDL program requirements. To illustrate, a recent survey of Provisional drivers in Queensland found that most drivers comply with GDL requirements such as passenger and mobile restrictions, however fewer drivers reported complying with general road rules, and speed limits in particular (Scott-Parker, Watson, King, & Hyde, under review a). Small group interviews and focus groups allow the road safety researcher to further

explore risky behaviours and attitudes reported by novice drivers and that have been found to contribute to increased crash risk. For example, younger drivers report that the *consequences* of their risky driving behaviour affects whether their friends or their parents would punish them. If 'nothing bad happened' such as a crash or an offence, the younger driver reported there would be no consequences. In contrast, a 'bad outcome' like a crash or a ticket from a Police Officer would likely incur additional punishment from parents and friends (Scott-Parker, et al., under review b). Naturalistic observations can not only provide information regarding the driver's behaviour immediately prior to crash involvement, they can also provide information regarding near-misses (Lee, Simons-Morton, Klauer, Ouimet, & Dingus, 2011). Such future research findings are vital for effective countermeasure development, and enhancement of GDL programs in particular.

For motorcyclists, the challenges for improving two-wheeled driving are large and complex, including improving road and vehicle safety, data and research, as well as socio-political dimensions (Harworth, in press). In regards to individual factors, there is a need for future research to develop effective approaches to ensure drivers ride in a manner that minimising risk. It may be suggested that the performance characteristics of high-powered motorcycles (e.g., acceleration, top speed) may attract individuals with risk-seeking propensities to use this form of transport more readily. There is also a need for more research to determine the most effective methods to enhance enforcement procedures to identify and reduce illegal risk taking by riders. As noted above, inexperience is also a major risk factor for motorcyclists and thus graduated licensing systems and driver training approaches need to be continually evaluated and reviewed to identify the approach that best minimising these risks. Future challenges also relate to identifying methods to ensure road designers and maintenance crews recognise the importance of removing loose material from roads and focusing on road repairs (Haworth, 2012). Research may also yet reveal that the accurate

identification and promotion of hazardous locations to motorcycle clubs may reduce casualty crashes (Government of Victoria, 2009). From an engineering point of view, challenges remain regarding developing roads and infrastructure that is forgiving to motorcycle drivers, particularly given the above research that indicates hitting stationary objects increases the risk of death for this driving group (Daniello & Gabler, 2011). There also remains the challenge for research to design safer motorcycles and associated driving wear e.g., helmets, light-weight padded clothing. This is particularly relevant for developing countries, where there is a need to ensure vehicles are safely maintained and helmet laws are effectively enforced (Haworth, 2012).

For the last group, there are also many things that need to be achieved for older drivers. Given the close relationship between age-related impairments and increased crash risk, researchers and members of the older driver community have advocated the need to better educate older drivers about driving safety and prepare them for the eventual cessation of their driving privileges. Further, while studies reviewed appeared to demonstrate moderate agreement regarding the influence of cognitive and visual risk factors on driving performance and crash involvement, other areas reviewed such as medical conditions and medication usage are inconsistent across studies. Most studies reviewed failed to acknowledge the interrelationship between cognitive, sensory and physical impairments and their influence on driving performance. The effects of age-related functional declines must not be considered in isolation. Cognitive, visual and physical impairments have a complex relationship; deficits in performance in one area may moderate the impairments of other factors. Thus, it is crucial to consider all the cognitive, visual and physical factors to provide a clearer view of how various functional declines influence driving performance among older drivers.

Investigations conducted on the self-monitoring processes of older drivers remains very limited, and often lack methodological rigour. Compared to research on older drivers'

driving capacity, very few studies focused on older drivers' self-monitoring beliefs and decisions on driving status. This could be achieved through either quantitative or qualitative methods. The few published studies in the area generally consist of small sample size, are retrospective in nature and lack objective measurements of driving behaviours. Whilst the consequences of driving cessation are widely reported to negatively impact the quality of lives of many older drivers (e.g. Freeman et al., 2006), very little is known about the process of driving restrictions and cessation. Given the rapidly growing population of older drivers, and their documented increase in both prevalence and severity of crash risk, it is important to gain more insight into the factors that influence older drivers' decisions on driving status and the effects those decisions have on them. Such knowledge may help to develop strategies and programs that promote awareness of driving-related factors common to older drivers and assist them to plan for eventual retirement from driving.

Finally, in regards to research influencing policy, and across all three vulnerable road user groups, there appears to be a lack of research that has developed clear recommendations on how best to convert research knowledge into evidence-based strategies to improve road safety. While the collective knowledge into the origins of crash risks for the three groups continues to expand, there needs to be complementary research that considers how best to utilise this new knowledge to have a practical effect on road users through the development and implementation of targeted and effective policies. The need to focus on building the bridge between conducting-research to informing-practice remains pertinent from when drivers are first attempting to be licensed until the time when decisions are made about whether they should cease being licensed. Such endeavours can only strengthen the relevance of the above research which aims to make a practical contribution to improving road safety.

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