Child and adolescent pedestrians and cyclists in Western Australia: how safe are they?

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Abstract
This study aimed to explore child and adolescent crashes in Western Australia (WA) from 2006-2016 involving 1,142 pedestrians and 755 cyclists at varying distances from the closest school. Distance between each crash and the closest school was calculated using a geographic information system. Age and gender of the crash victims, postcode level socio-demographic factors, and remoteness were included in the analysis. The results found that crashes within 500m of the closest school were more likely to occur during school zone operating hours (Monday to Friday, 7:30-9am, and 2:30-4pm). Child and adolescent pedestrian and cyclist crashes nearer to the closest school were more likely to occur in regional and remote areas than in Perth. The location of crashes relative to schools varied according to socio-economic status of the postcode of the crash. Continuing interventions are needed to develop infrastructure to support children and adolescents travelling safely, such as in high pedestrian and cyclist areas, and selectively reduced speed limits in areas where large volumes of young people travel on foot or by bicycle, such as close to schools, and in regional and remote areas of WA.

Keywords
Crash, Road Safety, Child cyclist, Child pedestrian

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EXECUTIVE SUMMARY

Introduction

Child and adolescent pedestrians and cyclists are classified as vulnerable road users both because of their age (developing motor and decision-making abilities) and because they are unprotected by an external protective device (such as the body of a motor vehicle). Questions remain about the safety of children and adolescents in Western Australia (WA), especially when travelling to school. A major barrier to active transportation to school, which has been repeatedly identified by researchers, is parents' concern about traffic safety. There is a need to identify when and where WA children and adolescents are involved in crashes, and which children are more likely to be involved.

Method

The aim of the study was to explore crashes involving child and adolescent pedestrians and cyclists, relative to the closest school, in WA over an 11 year period (2006 to 2016), identifying risk factors for these crashes including the age and gender of the child or adolescent involved in the crash; traffic volume and road network density levels; and postcode level socio-economic, demographic, and remoteness data. Pedestrians and cyclists are both identified as priority categories in the Towards Zero strategy (Office of Road Safety, 2009), and are high risk road user groups in both metropolitan and regional WA.

Objectives

The objectives of the study were as follows:

1. To describe the demographic, socio-economic, remoteness and crash characteristics of pedestrian and cycling crashes involving children and adolescents aged 0 to 17 years in WA from 2006 to 2016.
2. To determine the incidence of child and adolescent pedestrian and cyclist crashes in WA from 2006 to 2016.
3. To compare the difference in the median distance from child and adolescent cyclist crashes, and pedestrian crashes, to the closest school in WA from 2006 to 2016.

4. To calculate the risk of a child or adolescent pedestrian or cycling crash by distance to the closest school, in WA from 2006 to 2016, controlling for individual and area level characteristics.
5. To provide recommendations to improve road safety for children and adolescents particularly around schools, and encourage active transport to school.

The study used a longitudinal retrospective population-based study design. The study area was the state of Western Australia.

Data sources and processing

Crash data (including data on individual drivers, and longitude and latitude of each crash) for the period 1 January 2006 to 31 December 2016 for the entire state was extracted from the Integrated Road Information System (IRIS) database, which is maintained by Main Roads Western Australia.

A set of maps were created in ArcGIS, a geographic information system (GIS). Postal areas, the Australian Bureau of Statistics (ABS) approximation of postcodes (2012), were the administrative boundaries used in the GIS. The state was grouped by remoteness structure using the Accessibility/Remoteness Index of Australia Plus [ARIA+ - major cities, inner regional, outer regional, remote and very remote (Australian Population and Migration Research Centre, 2018)]. Data on school location and enrolment numbers were obtained from the Department of Education WA, and added to the maps. Crash data were added according to child or adolescent road user type (pedestrians or cyclists).

The road network distance between the closest school and each crash was measured in ArcGIS using the appropriate geoprocessing tools. Crashes were then allocated to one of four buffer zones around the closest school:

1. Within 500m of the closest school
2. More than 500m but up to 2km from the closest school
3. More than 2km but up to 5km from the closest school
4. More than 5km from the closest school

The number of intersections within a 1km straight-line distance of each crash was calculated in ArcGIS. Intersections within 1km was used as a measure of intersection density.

Traffic volume data at Western Australian intersections (AADT - annual average daily traffic) was obtained from Main Roads Western Australia. The AADT for each leg of each intersection was summed to calculate a total AADT for each intersection. The total AADT for the intersection closest to each crash was used as the estimated traffic volume for the site of the crash.

Postcode level socio-economic and demographic data were sourced from the ABS website and processed. All datasets were merged to enable statistical analysis.

<u>Statistical analysis</u>

Descriptive statistics were undertaken, including frequency distributions of crash types over time by age and gender of the child or adolescent; by time of day of crash; and median distance from crashes to schools. Incidence rates of children involved in crashes were calculated. Four logistic regression models were used to examine risk factors for child pedestrian and cyclist crashes, controlling for individual and postcode level demographic factors, postcode level socio-economic status and remoteness, school- and road-related factors. One model was created for each of the four buffer zones including crashes at defined distances from the closest school (up to 500m, >500m up to 2km, >2km up to 5km, and >5km).

Results

<u>Descriptive statistics</u>

Approximately one third of child and adolescent cyclists and pedestrians were involved in crashes which occurred during school zone hours (three hours per day, five days a week during term-time).

Higher numbers of male than female children aged 6 to 12 years and adolescents aged 13 to 17 years were involved in crashes as pedestrians and cyclists. The difference between numbers of males and females was even larger among the cyclists.

The highest proportion of crashes involving child and adolescent pedestrians and cyclists occurred in the postcodes in the lowest SEIFA tertile, that is, postcodes of lowest socio-economic status (38% of pedestrians, and 37% of cyclists). The lowest proportion of both crashes types occurred in postcodes in the highest SEIFA tertile (26% of pedestrians and 31% of cyclists).

Incidence rates

The incidence rates of child and adolescent pedestrians involved in crashes has dropped from 2006. The incidence rate for child and adolescent cyclists involved in crashes peaked in 2011. Incidence rates were higher for male children and adolescents involved in crashes, across all age groups. The difference was especially marked among male cyclists. Incidence rates rose with age for both cyclists and pedestrians. The highest incidence rates were in the Perth metropolitan area, followed by the outer regional areas. The lowest incidence rates were in the very remote areas.

Median distance from crash to the closest school

The median distance from crash to closest school was between 5 km and just over 6km for child and adolescent pedestrians and cyclists involved in crashes in Perth, and among female pedestrians and cyclists in all age-groups up to 17 years.

Median distance to the closest school tended to be higher among male cyclists involved in crashes aged under 6 and over 12 years of age. Median distances to the closest school were smaller in outer regional, and inner and outer remote areas for crashes involving pedestrians and cyclists.

Overall, median distance from a crash to the closest school was slightly larger during school zone operating hours for child and adolescent cyclists and pedestrians involved in crashes.

Number of pedestrian and cyclist crashes in buffer zones from the closest school

The highest proportion of crashes within 500m of the closest school occurred in primary school age children (6 to 12 years old). A total of 19 cyclists and 19 pedestrians aged 0 to17 years were involved in crashes within this buffer zone during the study period.

The highest proportion of both cyclists and pedestrians involved in crashes occurred in the 13 to 17 year old groups for the larger buffer zones. These proportions were noticeably higher in the cyclist groups >500m to 2km, and >2km to 5km from crash to the closest school.

The highest number of crashes occurred more than 5km from the crash to the closest school, with nearly double the number of pedestrians as cyclists (pedestrians=609 and cyclists=359).

Statistical models

Models showed that crashes occurring between 500m and 2km from the closest school were more likely to involve child and adolescent pedestrians while crashes which occurred between 2km and 5km from the closest school were more likely to involve child and adolescent cyclists.

Crashes which occurred within 500m of the closest school were more likely to occur during school zone operating hours.

Crashes were more likely to occur between 500m and 5km of the closest school in postcodes with a higher mean age.

Crashes which occurred up to 2km from the closest school were more likely to occur in regional and remote areas than in Perth. Crashes occurring between 2km and 5km from the closest school were less likely to occur in regional areas than in Perth.

Crashes occurring up to 5km of the closest school were less likely to occur in postcodes in higher SEIFA tertiles, while crashes occurring beyond 5km from the closest school were more likely to occur in postcodes of a higher socio-economic status.

Discussion

Unsurprisingly, nearly a third of children and adolescents were involved in crashes as pedestrians or cyclists during school zone operating hours, as this is the time they are exposed to traffic the most (LaScala et al., 2004, Congiu et al., 2008) because of attending school and school-related activities. The higher proportion of child and adolescent pedestrians and cyclists during school zone operating hours highlights the vulnerability of these children (Schwebel et al., 2012) compared to children and adolescents travelling in motorised vehicles.

The higher numbers and higher incidence rates of male children and adolescents aged between 6 and 17 years involved in crashes as pedestrians and cyclist may be explained by behavioural differences between males and females including higher risk-taking by male children and adolescents (Barton and Schwebel, 2007, Lin et al., 2017). These larger differences in numbers and incidence rates between male and female child and adolescents cyclists may be due to relatively more male children cycling than females (Munro, 2017).

The median distance from crash to closest school was more than 5km for most child and adolescent pedestrians and cyclists involved in crashes. A high proportion of crashes involving children and adolescents are therefore occurring some distance from the closest school. Since high volumes of school-aged children and adolescents cluster around schools, this suggests that traffic safety efforts around schools, including the time-based speed limits around schools and education programs on safety around schools, may be effective.

The results found that crashes involving child pedestrians and cyclists within 500m of the closest school were more likely to occur during school zone operating hours. This suggests that the higher numbers of children travelling on foot or by bicycle during this time close to school (travelling to and from school) leads to increased risk of involvement in a crash.

The results further found that pedestrians were at higher risk of involvement in a crash between 500m and 2km from the closest school, while cyclists were at higher risk between 2km and 5km from the closest school. The higher risk for pedestrians up to 2km is probably related to the distances commonly walked by children and adolescents who engage in active transportation to school as a pedestrian. Children and adolescents who cycle are likely to travel further, because of the greater speed and lower energy expenditure per unit distance travelled when cycling compared to walking.

Risk of children and adolescent pedestrians and cyclists being involved in crashes up to 2km from the closest school was higher in regional and remote areas compared to the metropolitan area, possibly related to less signage in and near school zone areas, and reduced compliance by drivers or enforcement of speed limits in school zone areas, plus higher speed roads near schools compared to Perth.

Crashes occurring up to 5km of the closest school were less likely to occur in postcodes in higher SEIFA tertiles, suggesting that more children residing in lower SEIFA postcodes may be walking and cycling to and from school, and that fewer protective measures for vulnerable road users in place in these areas.

Recommendations

"Toward Zero", the Western Australian road safety strategy for 2008 to 2020, identifies pedestrians and bicyclists as high priority categories which can benefit from interventions involving all four cornerstones of the Safe Systems road safety approach – 'safe road use(rs)', 'safe road and roadside', 'safe speeds' and 'safe vehicles'. Specific recommendations arising from this study relate to the first three of these cornerstones:

1. Maintain high levels of protection, including school crossing supervisors, speed limits and enhanced signage, within school zones and up to 500m from schools during the hours before and after school.
2. *The size of school zones may need to be reconsidered in regional and remote Australia*
3. Implement interventions to protect child and adolescent pedestrians and cyclists in areas beyond school zones with high volumes of pedestrians and cyclists.
4. Interventions should be tailored to the specific mix of child and adolescent pedestrian and cyclist traffic, and the socio-demographic profile of an area.
5. Continue to fund programs to educate and build road safety skills of school-aged pedestrians and cyclists.
6. Encourage and enforce the use of cycling helmets among child and adolescent cyclists.
7. Additional sources of data about cycling crashes should be explored for use in future studies. Addition data specific to pedestrians and cyclists should be collected in police crash reports.
8. Additional studies need to further explore the impact of area level socio-economic status on child and adolescent pedestrian and cyclist crashes.

Conclusion

This study explored child and adolescent pedestrians and cyclists involved in crashes, and how this differed according to distance from the closest school. Continuing measures are needed to enhance education of children and adolescence, selectively reduce speed, and develop infrastructure to support children travelling safely as pedestrians and cycling.

1 INTRODUCTION

Child pedestrians and cyclists are classified as vulnerable road users both because of their age (developing motor and decision-making abilities) and because they are unprotected by an external protective device (such as the body of a motor vehicle). A major barrier to active transportation to school, which has been repeatedly identified by researchers, is parents' concern about traffic safety (Ridgewell et al., 2009, Kirby and Inchley, 2009). A total of 143 child and adolescent cyclists and pedestrians were involved in crashes in Western Australia (WA) in 2016. There is a need to identify when and where these road users are involved in crashes, and which children and adolescents are more likely to be involved. This project involves the 'safe road use(rs)' cornerstone of the Safe System approach – involving drivers (parents, but also young drivers and older drivers), and their need to remain particularly alert among these vulnerable young road users, who are still learning how to handle traffic effectively. Furthermore it involves children, who need to learn to act responsibly and make good decisions when using the road as pedestrians and cyclists, but also are future WA motor vehicle drivers.

Children and adolescents spend much of their weekdays in and around schools. By identifying risk factors (both individual level and community level) for pedestrian and cyclist crashes relative to school location, children, adolescents and drivers can be better targeted for education programs about road rules, and increased awareness of traffic. Further, the specific needs of these vulnerable road users can be considered when planning infrastructure improvements, vehicle design and enforcement patterns. These findings have the potential to improve safety and reduce serious and fatal crashes involving children and adolescents.

1.1 Aims

The aim of the study is to examine the incidence of child pedestrian and cyclist crashes, relative to the closest school, in WA over an 11 year period (2006 to 2016). The study aims to identify risk factors for these crashes including the age and gender of the child or adolescent involved in the crash; traffic volume and road network density; and postcode level socio-economic, demographic, and remoteness data.

1.2 Hypotheses

The overall hypothesis of the study is:

H0: The location of crashes is not affected by proximity to schools, and does not differ by road user type and remoteness.

H1: The location of crashes is affected by proximity to schools, and differs by road user type and remoteness.

1.3 Objectives

The objectives of this study are:

1. To describe the demographic, socio-economic, remoteness and crash characteristics of pedestrian and cycling crashes involving children and adolescents aged 0 to 17 years in WA from 2006 to 2016.
2. To determine the incidence of child and adolescent pedestrian and cyclist crashes in WA from 2006 to 2016.
3. To compare the difference in the median distance from child and adolescent cyclist crashes, and pedestrian crashes, to the closest school, in WA from 2006 to 2016.
4. To calculate the risk of a child or adolescent pedestrian or cycling crash by distance to the closest school, in WA from 2006 to 2016, controlling for individual and area level characteristics.
5. To provide recommendations to improve road safety for children and adolescents particularly around schools, and encourage active transport to school.

2 LITERATURE REVIEW

With increasing rates of obesity (Gill et al., 2009), hours of screen time (Yu and Baxter, 2016) and reduced levels of physical activity (Department of Health and Ageing, 2012), public health experts are advocating that children and adolescents increase their levels of physical activity (Schrantz, 2015). Cycling and walking are considered forms of transport which have health benefits, including reducing obesity, improving cardiovascular health, reducing incidence of osteoporosis, type II diabetes mellitus, certain types of cancer, and reducing stress (Lee and Buchner, 2008). Cycling and walking for transport purposes, for example, to schools, parks and shops, is termed 'active transportation'.

All pedestrians and cyclists are classified as vulnerable road users and are at higher risk of traffic crash because they are unprotected by an external device that would *"absorb energy in a collision"* (pp. 1, Constant and Lagarde, 2010). Research in the European Union (EU) has shown that the risk of death is nine times greater when walking than when travelling by car (Breen, 2002).

Child and adolescent pedestrians and cyclists are even more vulnerable than adults. Various cognitive abilities are required to be safe pedestrians and cyclists. These include strong attentional processes (to attend to the relevant stimuli, particularly oncoming traffic), information processing, decision-making (for example, of a safe gap at an efficient speed), reasoning skills, and memory for road rules (to select where to cross the road) (Schwebel et al., 2012). Furthermore, pedestrians and cyclists need to judge vehicle speeds and visually detect potential dangers in the road environment (Schwebel et al., 2012). Concern about the safety of walking and cycling has been repeatedly identified as a barrier to child and adolescent active transportation and a concern of parents (Ridgewell et al., 2009, Kirby and Inchley, 2009, Kerr et al., 2006). However, there is little research into the crash risk associated with active transportation and proximity of these crashes to schools among children and adolescents in Australia.

2.1 Child and adolescent pedestrians

Unlike cycling, there are no regular, large-scale pedestrian participation surveys in Australia, so it is difficult to estimate the proportion of WA children and adolescent who regularly walk either for transportation or leisure purposes. Child and adolescent pedestrians are additionally vulnerable because of their less predictable behaviour, instability (they may stumble or fall due to, for example, an uneven surface), inexperience and a desire to take the easiest, most direct route across the road (which may not be the safest or most obvious route to motorists) (Breen, 2002).

2.1.1 Individual risk factors – age and gender

Poor road crossing skills may be related to lack of experience and developing cognitive and physical skills among younger children (Connelly et al., 1998). Gap selection is also a vital part of road crossing behaviour and children, particularly those under 10 years of age, may struggle to make consistent safe decisions (Connelly et al., 1998). A study of 71 children and their parents in Melbourne using a driver simulator found that younger children (aged six to seven years of age) displayed more risky behaviour and poorer road crossing decision-making than older, more experienced children of eight to ten years old (Oxley et al., 2007). The study found that the younger children were twelve times more likely to make unsafe crossing decisions than the older children (Oxley et al., 2007). Younger children (six to eight year olds) and shorter older children struggle to see over parked cars and obstacles (Congiu et al., 2008) which affects their road crossing decisions.

Among very young children (those less than five years old), fatalities tend to occur when a child is backed over by a reversing family vehicle, rather than ‘darting-out’ into the traffic or following an incident of poor judgement (Brison et al., 1988, Schwebel et al., 2012).

Among adolescents aged 10 to 19 years old, risks leading to pedestrian crashes are more similar to those of adults, such as walking at night, walking while under the influence of alcohol or drugs, and when distracted, for example, by mobile phones (Sleet et al., 2010).

An analysis of 8,178 police reported child and adolescent pedestrian serious casualty crashes (aged 0 to 17 years) in Victoria between 2000 and 2010 found that a higher proportion of crashes occurred at a mid-block location (59%) than at an intersection (40%) (Oxley, 2012). Lightstone (2001), in a study of 610 motor vehicle/pedestrian crashes in the United States (US), found that children under five years of age were more likely to be hit at a midblock location, while older children and young adolescents (five to fourteen years of age) were more likely to be hit at an intersection. The study also found that intersection crashes tended to occur further from the pedestrian’s home while midblock crashes tended to occur within 200 metres of home (Lightstone et al., 2001).

A study in the US comparing the simulated road crossing behaviour of 85 children (aged 5 to 8 years old) and 26 adults (19 to 37 years old) found that girls waited longer before crossing and paid more attention to the traffic, while boys missed fewer opportunities to cross than girls (Barton and Schwebel, 2007). Boys are also expected to take greater risks and tend to be more impulsive than girls (Barton and Schwebel, 2007), although a study in Melbourne found no gender differences associated with incorrect road crossing decisions (Oxley et al., 2007).

Studies have shown that younger children have a higher risk of hospitalisation resulting from an injury as a pedestrian than older children (Poulos et al., 2012, Hobday and Knight, 2010). A study of 1,240 injured pedestrians aged 14 or less, in a large South African metropolitan area, found the highest pedestrian injury incidence rates and case fatality among five to nine year olds (Hobday and Knight, 2010). Male children in this age group had higher injury and fatality risk (184 per 100,000 and 11 per 100,000 respectively) than female children (133 per 100,000 and 10 per 100,000 respectively). A study from New South Wales between 2000 and 2005 found the highest crude hospitalisation among one to four year olds, and five to nine year old boys (30 and 29 per 100,000 boys respectively) and the lowest among five to nine year old girls (16 per 100,000 girls) (Poulos et al., 2012). These results suggest that boys tend to demonstrate more impulsive, less controlled behaviour, putting them at greater risk of unintentional injury. Furthermore, girls are more likely to attribute injuries to their own behaviour than boys, leading to more frequent repeated risky behaviour among boys (Barton and Schwebel, 2007).

2.1.2 Socio-economic status and the built environment as risk factors

Children and adolescents exposed to areas with a lower socio-economic status (Braddock et al., 1991, LaScala et al., 2000, Rothman et al., 2014b), living in areas with higher proportions of households with a low incomes (LaScala et al., 2004), female-headed (Braddock et al., 1991), multifamily households (Mueller et al., 1990, Agran et al., 1996) and with high minority populations (Cottrill and Thakuriah, 2010, Braddock et al., 1991) were at an increased risk of involvement in a pedestrian crash. In contrast, children and adolescents in areas with higher proportions of households with higher incomes were at lower risk of a pedestrian or cyclist crash (LaScala et al., 2004). Greater population density (Lightstone et al., 2001) and youth population density (aged 0 to 17 years) were associated with a greater risk of child pedestrian and cyclist crashes (LaScala et al., 2004). Individual level socio-economic status, including family overcrowding, poor family support and family stress, was also associated with a higher risk of child pedestrian injury (Christoffel et al., 1996). The increased risk to pedestrians associated with lower socio-economic status may be due to the exposure to and nature of the road environment, including the volume of traffic, the presence of visible obstacles and absence of footpaths (Stevenson et al., 1996), as well as the absence of safe play areas (Bagley, 1992).

Streets with high speed vehicles (for example, in the highest tertile of recorded speed) (Mueller et al., 1990, Agran et al., 1998, Donroe et al., 2008) and large amounts of street parking (blocking visibility) were associated with an increased risk of child and adolescent pedestrian injuries (Agran et al., 1998, Roberts et al., 1995, Stevenson, 1997). Previous research in England found that the secondary retail and high density residential land use types were associated with child and adolescent pedestrian injuries (Dissanayake et al., 2009).

A meta-analysis found that the built environment was directly associated with risk of pedestrian injury (DiMaggio and Li, 2012). The authors suggested that small changes to the roadway environment such as road narrowing, speed bumps and signage changes would reduce child and adolescent pedestrian crash and injury risk (DiMaggio and Li, 2012). A further review found that traffic calming and access to playgrounds or recreation areas were associated with both increased walking and reduced injury to pedestrians (Rothman et al., 2014a).

When the effects of socio-economic status and population density were accounted for, increased walking to school was not associated with increased risk of pedestrian crashes (Rothman et al., 2014b). However, pedestrian crashes frequently occur on the way home from school or when playing after school (Congiu et al., 2008). A study in Canada, examining 2,717 crashes involving pedestrians under 18 years, found that the highest number of pedestrian crashes per unit area (including fatal crashes) occurred within 150m of a school (Warsh et al., 2009). The number of child and adolescent pedestrian crashes per unit decreased as the distance from schools increased (from 1,039 crashes per $100km^2$ up to 150m from the school, to 183 crashes per $100km^2$ more than 451m from the school). Almost 50% of the crashes occurred during school travel times (7am to 9am, 12 noon to 1pm, and 3pm to 5pm).

Previous research of 717 pedestrian and cyclist crashes among under 16 year olds in California found a higher annual rate of pedestrian and cyclist crashes during school term time than during holiday periods (LaScala et al., 2004). High rates during term-time were associated with higher youth density and greater numbers of middle schools (catering for children aged 11 to 14 years old) (LaScala et al., 2004).

Australian research has shown that children and adolescents with more experience with independent travel as a pedestrian are less likely to make critically incorrect road crossing decisions (Oxley et al., 2007). Parent supervision appears to reduce risk of pedestrian injury, while crossing streets with peers increases risk of crash involvement (Schwebel et al., 2012).

2.1.3 Driver and vehicle related risk factors

Driver behaviour and attitudes towards pedestrians also play a role in crashes involving child and adolescent pedestrians. The behaviour of younger pedestrians may be unpredictable so more difficult for drivers to handle (Breen, 2002). There is a perception that vehicles have higher status on the road than pedestrians (Congiu et al., 2008), with drivers failing to give right of way to pedestrians and driving at high speeds in high pedestrian dense areas (Preusser et al., 2002). Speed affects the likelihood and severity of crashes involving pedestrians. Low speed crashes involve primarily young child and older adult pedestrians. Higher speed crashes, which result in more severe injuries, are more common in older children, adolescents, young- and middle-aged adults (Rosén et al., Tefft, 2013).

Furthermore, children are less visible than adults because of their smaller size. Primary school-aged pedestrians are frequently injured when stepping out into the street between two parked cars (Leden et al., 2006). In particular, the large bonnets of vehicles such as sports utility vehicles (SUVs) make seeing child pedestrians more difficult.

2.1.4 Type of pedestrian injuries

Most pedestrian injuries involve the head and the lower extremities (Hu and Klinich, 2015) due to the frontal design of vehicles which effects both the location and severity of injuries to pedestrians (Breen, 2002). Most head injuries result from contact with the bonnet (particularly among children) of the car, the windshield and A-pillars. However, the majority of lower limb extremities injuries are due to contact with the front bumper of the vehicle (Hu and Klinich, 2015). Frontal design of cars such as a SUV are particularly an issue for young pedestrians as the height results in more severe injuries to the chest and head areas (Breen, 2002), and higher risk of being killed compared to other car types (Martin et al., 2011). The presence of rigid bull-bars on many four wheel drive and utility vehicles also contribute to fatal pedestrian crashes [cited by (Congiu et al., 2008)].

2.2 Child and adolescent cyclists

Cyclists are inherently vulnerable road users, because of the fragility of the (unprotected) human body (Wegman et al., 2012). Cyclists can lose control, especially at higher speeds, and fall easily. Lack of experience increases risk of a crash. Child and adolescent cyclists are at even higher risk because of these factors than adult cyclists. Younger children have less capacity to respond to unexpected events such as vehicles pulling out suddenly or travelling faster than expected, or losing their balance on their bicycles, than adults. Furthermore, younger cyclists, particularly those still in primary school, are still learning cycling skills to deal with complex traffic situations (Mandic et al., 2016).

The Cycling Participation Survey 2017, which included 475 households in WA, found that children and adolescents have a higher cycling participation rate (defined as having ridden in the week before the survey) than Australia overall. Among children under 10, 42% of children in Perth and 63% of those in regional WA had ridden in the previous week, compared to 41% overall in Australia (Munro, 2017). Rates were slightly lower among 10 to 17 year olds with 36% in Perth, 42% in regional WA and 33% in Australia overall. Participation rates were higher among males than females, although this was less marked in regional WA than in Perth.

2.2.1 The scope of child and adolescent cycling research in Australia

Both in Australia and internationally, research into cyclist safety has focused on helmet use (Chaney and Kim, 2014, Macpherson and Spinks, 2008) and across all age-groups – examples in Australia include research by Lawrence (2015) and Rome et al. (2014) – rather than focusing specifically on children and adolescents.

Child and adolescent cyclist safety has been examined in terms of safety equipment and roadworthiness of bicycles [e.g., a study in New Zealand among 8 to 12 year old cyclists (Bromell and Geddis, 2017)], education programs and evaluations [e.g., a study in the US targeting 8 to 12 year olds (Lachapelle et al., 2013)], and road safety knowledge (Dong et al., 2011, Morrongiello et al., 2008). The studies focusing on child cycling injuries are frequently country-specific, for example, studies in Canada (Pless et al., 1989), the USA (Rivara et al., 1997), Taiwan (Wang et al., 2009) and China (Dong et al., 2011). Furthermore, the context of cycling varies widely across the world, with some countries, for example, the Netherlands, having very high cycling participation rates, and other countries, for example, Japan, having high rates of children and adolescents using cycling as active transport especially to school.

Because of differing utilisation patterns, it is difficult to generalise findings from countries with high child cycling participation levels to countries with lower cycling participation levels among children and adolescents.

Despite high cycling participation rates in WA (Munro, 2017), there is little research into child and adolescent cycling safety in WA (Trapp et al., 2011, Schoeppe et al., 2015). Trapp and colleagues (Trapp et al., 2011) undertook a cross-sectional survey of children in year five to seven, in the Perth metropolitan area. They examined the distance children lived from school (a mean distance of 1.7km from home to/from school), and found that more male children than female children cycled to school at least once a week (31% compared to 15%). Boys were more likely to cycle to school in neighbourhoods with high (street network) connectivity and low traffic volumes.

Trapp and colleagues explored the barriers to cycling, which included distance to school, the convenience of driving to parents, and parents' perceptions of their children's cycling ability and the environment. Further research in the Melbourne metropolitan area examined predictors of and barriers to cycling to school (Hume et al., 2009, Carver et al., 2014), which included knowing many people in their community. Carver and colleagues (Carver et al., 2014) highlighted the important role that parents play as 'gatekeepers' of children's and adolescent's mobility (and therefore the frequency and the distance of cycling) outside the home. Ridgewell and colleagues (Ridgewell et al., 2009), examined parental choice about both cycling and walking among eight to eleven year old children in Brisbane. They found that the concerns about possible assault and danger from increased traffic were the most important reasons why children were driven by their parents, and that distance was less of a barrier than parental safety concerns (Ridgewell et al., 2009). Research conducted in Queensland showed that parents believed that children should be at least 10 years old before cycling or crossing a road independently (Soole et al., 2011). Timperio and colleagues identified other barriers to independent travel among primary school children in Melbourne, including busy intersections, poor access to crossings and more direct routes through other means of transport (Timperio et al., 2006). The results showed that children were more likely to actively commute to school if they had to travel less than 800 metres each way (Timperio et al., 2006).

2.2.2 Individual risk factors – age and gender

Very young children (aged three years old and younger) are often transported on bicycle-mounted child seats or towed child trailers (Oxley et al., 2016, Powell and Tanz, 2000). A study in the US examining injuries of 49 children transported in bicycle seats (88%) or towed trailers (12%) over a nine year period found that the mean age of injured children was 2.4 years (Powell and Tanz, 2000). The results suggest that the incidence of injury was low, with those associated with bicycle-towed child trailers (0.3 per 100,000 children under five years old) being less common than injuries in bicycle seats (1.3 per 100,000 children under five years old).

A recent study of police-reported and hospitalised cyclists crashes in Victoria found that adolescents have the highest rates of bicycle-related crashes (33 per 100,000) compared to younger children (aged under 10 years – 5 per 100,000) and adult cyclists (aged 20 years and more – 27 per 100,000) (Boufous et al., 2011). This is possibly due to adolescents' greater risk-taking behaviour and higher exposure through cycling longer distances than younger children. More than 80% of cyclists (of all ages) involved in crashes were male (Boufous et al., 2011). A study in the US of 7 to 15 year olds found that older participants, and those who had experience riding a bicycle with a parent, had higher scores on a bicycle safety behaviour survey than others (Lachapelle et al., 2013).

Research from the US from 20 years ago [which has recently been republished (Rivara et al., 1997, Rivara et al., 2015)] showed that children younger than six years of age were at high risk of serious injury compared to older children (6 to 12 years), adolescents (13 to 19 years) and adults (20 to 39 years). Cycling at higher speeds (above 20km/h) and collision with a motor vehicle were also significant risk factors for serious injury (Rivara et al., 1997). In the Netherlands, the highest proportion of fatalities among children and adolescents (aged 0 to 19 years old) was in the age-group 6 to 14 years (Wegman et al., 2012), which represented 14% of all road traffic fatalities in this age-group.

An analysis of 38,699 cyclist crashes in Spain found that those under the age of 20 years old were more likely to be involved in crashes as the 'responsible person' than middle-aged cyclists, with the largest effect size in the group under 10 years of age (Martínez-Ruiz et al., 2013). Those aged 10 to 19 years old were more likely to be involved in single vehicle crashes while committing an infraction than middle-aged cyclists (Martínez-Ruiz et al., 2013). Results in several studies found that males of all ages were more likely to be involved in all cycle crashes than females (Rivara et al., 1997, Martínez-Ruiz et al., 2013, Lin et al., 2017).

2.2.3 Socio-economic status and the built environment as risk factors

There has been little Australian research into population level factors which affect crashes involving child and adolescent cyclists. Previous research undertaken in the US showed that fewer years of parental education, poor parental supervision and a history of a crash to a family member were associated with an increase in cyclist injuries among 0 to 14 year olds (Pless et al., 1989). Other factors significantly associated with child and adolescent cyclist crashes (in the US) were neighbourhood ethnicity, population density and the presence of public transportation (Chaney and Kim, 2014). A study in the US comparing the differences in crash risk factors among cyclists and pedestrians (both adult and child) found that population density and lower education levels (not completing high school) were associated with higher concentrations of cyclist crashes than pedestrian crashes (Delmelle et al., 2012). A study in Hungary investigated the effect of so-called demographic density (that is, population density) on use of safety devices and the nature of injuries on cycling injuries in 1 to 18 year olds (Kiss et al., 2010). The authors showed that in villages (with a lower population density), fewer children wore helmets, head injuries were more frequent, and more injuries involved bicycle spokes.

2.2.4 Cyclist behaviour as a risk factor

A recent study of 2,075 middle school children (aged primarily between 14 and 16 years) in rural China, who primarily travelled to school by bicycle, found that a high proportion participants (28%) had sustained an injury while travelling on a bicycle. A higher proportion of children who rode faster than 20km/h (79%) or slower than 10km/h (55%) were involved in bicycle crashes compared to those travelling between 10km/h and 20km/h (24%)(Lin et al., 2017). Those who were tired and experiencing a negative mood such as anger were also at a higher risk of involvement in a cycling crash (Lin et al., 2017).

A survey of more than 3,000 Japanese high school students who commuted to school by bicycle found that using a mobile phone while cycling was quite common among students commuting to school, with 87% of participants having used a mobile phone while riding, since entering high school (Ichikawaa and Nakahara, 2008). Male students were more likely than female students to have used a mobile phone while cycling in the last month. Participants who had *"ever used a mobile phone while cycling to school"* were more likely to have experienced a crash or near-miss (Ichikawaa and Nakahara, 2008). Interestingly, mobile use is illegal while driving a motor car or motorcycle, but not while riding a bicycle in Japan (Ichikawaa and Nakahara, 2008).

2.2.5 Type of cyclist injuries

Results from Israel showed that child and adolescents cyclists (aged 0 to 17 years old) involved in crashes with motor vehicles were more likely to have head, face and neck or spine injuries than cycling crashes that did not involve motor vehicles (Siman-Tov and Jaffe, 2012). Research in Taiwan including a group of 324 children and adolescents (0 to 18 years old) with head injuries following a cycling crash found that a significantly higher proportion of males had severe head injuries (Glasgow Coma Scale of eight or less) than females (34% compared to 23%), and a significantly higher proportion of 5 to 9 year olds had severe head injuries than 10 to 14 year olds (65% compared to 6%) (Wang et al., 2009). Recent Australian research examined injuries in child cyclists aged 10 years and under who visited or were admitted to hospital (Oxley et al., 2016). Significantly larger proportions of children aged 7 to 10 years had injuries to the arms, wrists and hands than younger children, while significantly higher proportions of children aged three years and under sustained head injuries than older children (Oxley et al., 2016).

2.3 Conclusion

While a great deal of research has been done examining child and adolescent pedestrian and cyclist safety, there are gaps in the literature, particularly regarding cyclists. There is also minimal research to date about the crash risk to these vulnerable road users specific to WA. Much of the research in this area is from other countries, with the majority originating in the US, which limits the applicability of the research to the WA situation. Differences such as the very high urban population in Australia compared to the US, road design features (for example, the use of roundabouts), road design speed, distances travelled by the average driver per year and enforcement (Marshall, 2018) may lead to differences in road safety outcomes between countries. While there have been studies about the individual characteristics of child and adolescent pedestrians (such as age and gender) involved in crashes, there are fewer studies specific to child and adolescent cyclists. Research into individual level factors about child cyclist crashes have tended to use hospitalisation data rather than police data. As a result, less is known about details of these crashes or about crashes involving children and adolescents who were not hospitalised. The timing and location of child and adolescent pedestrians have been explored but these two factors have not been simultaneously examined. Research into active transportation, including to schools, has primarily used survey data, which is prone to recall bias and social desirability bias. With a few notable exceptions [e.g., studies by Warsh, Rothman and colleagues (2009)], there has been less research into crash risk using more objective sources of data and little research in crash risk relative to schools. Finally, remoteness and its association with child and adolescent crash risk, both internationally and in Australia, has not been examined and there has been limited research into the role of socio-economic status on child and adolescent crash risk in Australia.

This study aims to examine the impact of crash time and location, specifically as relating to schools, socio-demographic factors and remoteness. Unlike most previous studies in this area, the factors will be examined simultaneously. By identifying risk factors (both individual level and community level) for crashes among child pedestrians and cyclists, policies can be developed targeting the most important problem areas. This has the potential to improve safety and reduce serious and fatal crashes involving children.

3 METHODS

3.1 Study Design

A retrospective population-based study was undertaken on child and adolescent pedestrian and cycling crashes aged 0 to 17 years from 2006 to 2016. The study area was the state of Western Australia (WA).

3.2 Data Collection

De-identified crash data from January 2006 to December 2016 was accessed through the Integrated Road Information System, which is maintained by Main Roads Western Australia (referred to hereafter as Main Roads). Postcode level demographic and socio-economic data was obtained from the Australian Bureau of Statistics (ABS) website. Spatial data, which included postcode boundaries, intersection locations and road centreline shapefiles[1], were obtained from the ABS and Main Roads. A list of all operating public and private schools, their physical addresses and enrolment numbers was obtained from the Department of Education Western Australia. All analyses was undertaken using de-identified data.

3.3 Databases

3.3.1 Integrated Road Information System (IRIS)

The data was extracted from the IRIS database which contains detailed information on the characteristics of the vehicles involved in road crashes, crash circumstances, police reported injury and road information related to the crash location. No data is available for residential address or safety equipment (such as cycling helmet) usage for road users. For the purposes of this study, unit record information was acquired for each child aged 17 years or younger involved in a crash either as a pedestrian or a cyclist. Specific data used for this study included: sex; age; road user type; date; time; and location details (including longitude and latitude) of crash; and all information on the nature and circumstances of each crash.

The records for crashes which occurred during school zone operation times were flagged, using state school term dates for each year included in the study. For a crash to be flagged as being during school zone operating hours, it had to occur:

- From Monday to Friday
- Between 7:30am and 9am, or between 2:30pm and 4pm
- During state school term-times for the relevant year

[1] A shapefile is a geospatial data format used for geographic information system (GIS) software.

3.3.2 School listings and database

A list of all public and private WA schools was obtained for each year from the Department of Education. A unique identifier was provided for each school which also allowed identification of schools which had changed names during the study period. Other fields included: school name, street address (missing in a high percentage of records), suburb, postcode, telephone number, school classification, lowest and highest school level enrolled, and total student numbers per school.

Using the Main Roads Western Australia 2016 school shapefile, each school address was located on a map of WA (using longitude and latitude co-ordinates). For those schools which a match could not be found, street addresses were batch geocoded using the mappify[2] web application (2016). Google Maps, the Department of Education website and individual school websites were used to locate schools without street addresses. Schools which failed to geocode were manually geocoded using Google Maps. School which had changed names were identified using the unique identifier.

Enrolment numbers of students for each year were retained and used in the statistical models, because schools with higher enrolment numbers indicated the presence of more children who were exposed to risk of a crash.

3.3.3 Shapefiles

Various additional shapefiles[1] were required to create 'layers' of data in the geographic information system[3] (GIS) which were required to calculate distance between each crash and the closest school, and the number of intersections near each crash. The 2016 ABS postal areas shapefile was obtained from the ABS website. The 2016 road centrelines and intersection shapefiles were acquired from Main Roads.

[2] mappify is a simple geocoding and routing web-based tool for Australia which uses the freely available G-NAF (Geocoded National Address File) to forward and reverse geocode, that is, convert street address to geographic co-ordinates and vice versa.

[3] A GIS is defined as *'a constellation of hardware and software that integrates computer graphics with a relational database for the purpose of managing data about geographic locations'* RIPPLE, W. J. 1989. *Fundamentals of Geographic Information Systems : a Compendium* Bethesda, Md., American Congress on Surveying and Mapping

3.3.4 Area level socio-economic and demographic data

Aggregate (postcode level) socio-economic and demographic data was obtained from the ABS Census website, using the Tablebuilder tool (ABS, 2015) to control for neighbourhood factors in the statistical models. Three years of census data was used (2006, 2011 and 2016). The following variables were acquired (at postcode level): number of residents by age and gender; number of residents by Indigenous status; and SEIFA (Socio-economic Indexes for Areas - ABS, 2013) Index of Relative Socio-economic Advantage and Disadvantage (IRSAD) scores (see Appendix 7.1 for description of the SEIFA). Data for the intermediate (non-census) years were calculated using linear interpolation methods, in Stata 15. This created estimates of the socio-economic and demographic data for the non-census years. A final dataset of postcode level variables was created for use in the statistical analysis. These included SEIFA level (in tertiles, with tertile one being the lowest postcode level socio-economic status), proportion of population of Indigenous origin, total population aged 17 years and younger, and postcode mean age.

The list of the remoteness classifications of WA postcodes were obtained from the ABS website. Crash location was defined as being in a major city of Australia (that is, Perth), inner regional, outer regional, remote and very remote, based on the ARIA+ measure of remoteness (Australian Population and Migration Research Centre, 2018). The ARIA+ is based on road distance measurements from populated localities to the nearest Service Centre. It excludes consideration of socio-economic status and population sizes (Australian Population and Migration Research Centre, 2018).

3.4 Creation of maps using the GIS

A series of maps were created in a GIS (ArcGIS 10.4) – one map per year of study (11 years). The ABS postal area boundaries, road centrelines and intersections were added to each map. The relevant child and adolescent crashes were plotted on each year's map, separately for crashes involving pedestrians and cyclists. Locations of schools were added.

These maps were used to undertake distance calculations. The distance between each crash by type (crashes involving child and adolescent pedestrians, and crashes involving child and adolescent cyclists) and the closest school were measured in ArcGIS by calculating road network distance using the relevant geoprocessing tools. Crashes were then allocated into four buffer zones from the closest school:

1. Within 500m of the closest school
2. More than 500m but up to 2km from the closest school
3. More than 2km but up to 5km from the closest school
4. More than 5km from the closest school

The average length of a school zone is up to 200m from the school (when the school zone speed limit is 40km/h) or 300m from the school (when the school zone speed limit is 60km/h) (Main Roads Western Australia, 2014). Initially, the first buffer included crashes within 200m of the closest school. An alternate first buffer included crashes within 300m of the closest school. However, the small number of crashes resulted in issues with the models as age, remoteness and year categories were empty, and observations were excluded. As a result, a larger first buffer zone (500m) was chosen for the final model, but these preliminary models are displayed in the appendix.

3.4.1 Road density measures

Using the Main Road Western Australia intersection shapefile, the number of intersections within a 1km straight-line ('as the crow flies') distance of each child crash was obtained. This count (intersections within 1km of a crash) was used as a measure of intersection density.

3.4.2 Traffic volumes

Traffic volume data at WA intersections (annual average daily traffic - AADT) were obtained from Main Roads. AADT is the annual average daily traffic experienced by each leg of an intersection, and is recorded and maintained by Main Roads. The AADT for each leg involved in each intersection was summed to calculate a total AADT for each intersection. The road network distance from each crash to the closest intersection was calculated in ArcGIS. The total AADT for the intersection closest to each crash was used as the estimated traffic volume at the site of the crash.

3.5 Statistical analysis

Descriptive statistics (including frequency distributions of crash types over time by age and gender, and by school zone, median distance from crashes to schools and number of crashes per zone from the closest school) were undertaken.

A series of four logistic regression models were used to examine individual, school and neighbourhood risk factors for child pedestrian and cyclist crashes, at different distances from the closest school to each crash. The four models are identified below.

1. A model using buffer zone one which included crashes occurring up to 500m from the closest school,
2. A model using buffer zone two which included crashes occurring more than 500m but up to 2km from the closest school
3. A model using buffer zone three which included crashes occurring more than 2km but up to 5km from the closest school
4. A model using buffer zone four which included crashes occurring more than 5km from the closest school to the crash.

The outcome variable for each model was if the pedestrian and/or cyclists crash occurred in the relevant buffer zone, or if the crash occurred outside the buffer zone.

3.6 Ethics approval

Ethics approval was obtained from the Curtin Human Research Ethics Committee. Approval was granted on 2 June 2017. The approval number for the project is HRE2017-0330.

4 RESULTS

4.1 Overview

Between 2006 and 2016, a total of 52,296 children and adolescents aged 0 to 17 years were involved in a crash (Table 1). Of these, 1,142 (2.2%) were pedestrians and 755 (1.4%) were cyclists. The remainder were child and adolescent passengers and drivers.

A higher proportion of child and adolescent pedestrians (with age and gender recorded) involved in crashes were male (n=627, 57% - Table 1) in 2006 to 2016 compared to females (n=466, 43%). A higher proportion of child and adolescent cyclists also involved in a crash were males (n=608, 83%) than females (n=127, 17%).

Among female children and adolescents involved in crashes, the highest proportion of crashes involving pedestrians were among the 13 to 17 year olds (n=274, 2.7% of all child crashes), compared to 2.1% (n=123) in the 6 to 12 year old age group. The highest proportion of female cyclists involved in crashes were in the 6 to 12 year old age group (n=58, 0.98% of all child crashes), followed by the 13 to 17 year olds (n=62, 0.61%).

Among male children and adolescents involved in a crash, the highest proportion involved in both pedestrian and cyclist crashes were in the 6 to 12 year old age-group (n=196, 3.2%, and n=207, 3.4% of all child and adolescent crashes respectively).

In 2016, there were 1,109 schools (including kindergartens, primary schools, high schools and other schools, government and private), attended by a total of 446,826 students. Of these students, 79 (0.017%) were involved in a crash as a pedestrian and 64 (0.014%) were involved in a crash as a cyclist (Table 1).

Table 1: Descriptive statistics of children and adolescents involved in pedestrian and cyclist crashes by sex and age group[1] in Western Australia from 2006 to 2016

	Sex	2 years and younger n (%)	3 to 5 years n (%)	6 to 12 years n (%)	13 to 17 years n (%)	Total n (%)
Pedestrians	**Female**	22 (0.77)	47 (1.6)	123 (2.1)	274 (2.7)	466 (2.1)
Cyclists		1 (0.035)	6 (0.21)	58 (0.98)	62 (0.61)	127 (0.60)
Total[2]		2,841 (100)	2,901 (100)	5,917 (100)	10,238 (100)	21,897 (100)
Pedestrians	**Male**	29 (1.0)	73 (2.33)	196 (3.2)	329 (2.4)	627 (2.4)
Cyclists		4 (0.14)	19 (0.61)	207 (3.4)	378 (2.8)	608 (2.4)
Total[2]		2,868 (100)	3,128 (100)	6,068 (100)	13,599 (100)	25,663 (100)

[1] Age and gender data was missing for 4.3% of pedestrian records and 2.6% of cyclist records.
[2] Total includes all children and adolescents involved in crashes (pedestrians, cyclists, passengers and drivers)

Table 2 shows the number of children and adolescents involved in pedestrian and cyclist crashes by remoteness across WA. The majority of children and adolescents involved in pedestrian and cyclist crashes were located in Perth (n=973, 86% and n=603, 80% respectively). The proportion of children and adolescents involved in cyclist crashes was higher than the proportion involved in pedestrian crashes in all areas other than Perth. For example, inner regional WA had 5.7% of children and adolescents involved in pedestrian crashes but 8.3% of children and adolescents involved in cyclist crashes. The lowest number of children and adolescents involved in these crashes were in very remote WA (6 pedestrians and 11 cyclists).

Table 2: Descriptive statistics of children and adolescents involved in pedestrian and cyclist crashes by remoteness in Western Australia from 2006 to 2016

Remoteness	Perth n (%)	Inner Regional n (%)	Outer regional n (%)	Remote n (%)	Very remote n (%)
Pedestrians	973 (86)	65 (5.7)	62 (5.5)	28 (2.5)	6 (0.53)
Cyclists	603 (80)	63 (8.3)	55 (7.3)	23 (3.0)	11 (1.5)
Total	1,576 (83)	158 (84)	117 (6.2)	51 (2.7)	17 (0.90)

Table 3 shows the number of children and adolescents involved in pedestrian and cyclist crashes by postcode-level socio-economic status (SEIFA) tertiles. The highest proportion of crashes involving child and adolescent pedestrians and cyclists occurred in the postcodes in the lowest SEIFA tertile (424 pedestrians, 38% and 274 cyclists, 37%). The lowest proportion of crashes involving child and adolescent pedestrians and cyclists occurred in the postcodes in the highest SEIFA tertile (297 pedestrians, 26% and 235 cyclists, 31%). Additional maps demonstrating crashes and SEIFA tertiles are in the Appendix (Maps 7 and 8).

Table 3: Descriptive statistics of children and adolescents involved in pedestrian and cyclist crashes by postcode level socio-economic status in Western Australia from 2006 to 2016

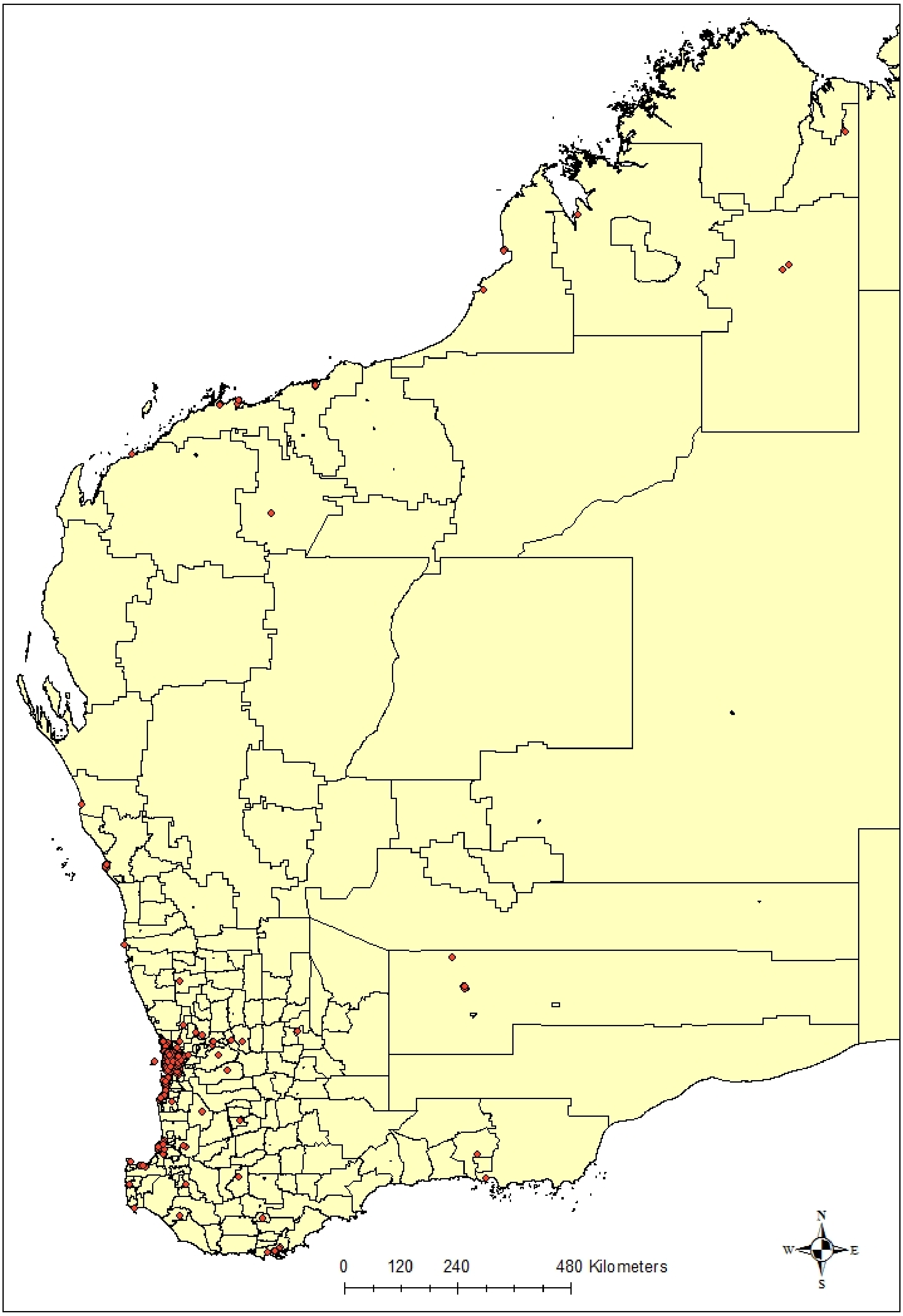
SEIFA	Tertile 1 n (%)	Tertile 2 n (%)	Tertile 3 n (%)
Pedestrians	424 (38)	401 (36)	297 (26)
Cyclists	274 (37)	241 (32)	235 (31)
Total	698 (37)	642 (34)	532 (28)

The location of individual child and adolescent pedestrian and cyclist crashes between 2006 and 2016 are shown in Map 1 to 2 and Map 3 to 4 respectively.

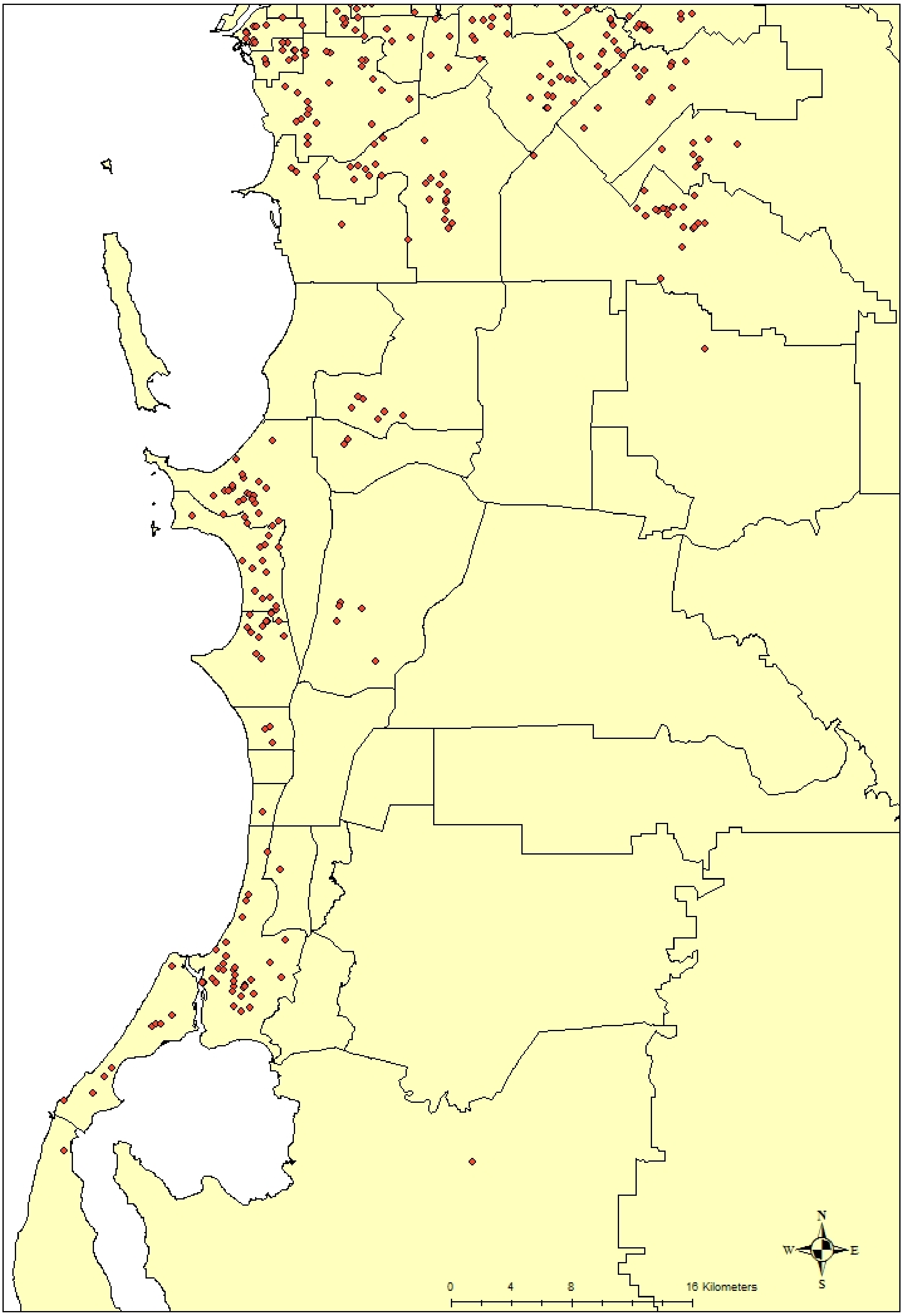
Map 1 shows the location of all crashes involving child and adolescent pedestrians across the study period. While most crashes occurred in the Perth metropolitan area, several crashes occurred in Kalgoorlie/Boulder, Albany, Busselton/Dunsborough, Bunbury, Geraldton and Karratha.

Map 2 and 3 show the locations all child and adolescent crashes occurring in the metropolitan area. Clusters of crashes occurred in Mandurah, Rockingham and Kwinana, Armadale, Cannington, near the CBD, Balga/Girrawheen, Ellenbrook and Quinns Rocks.

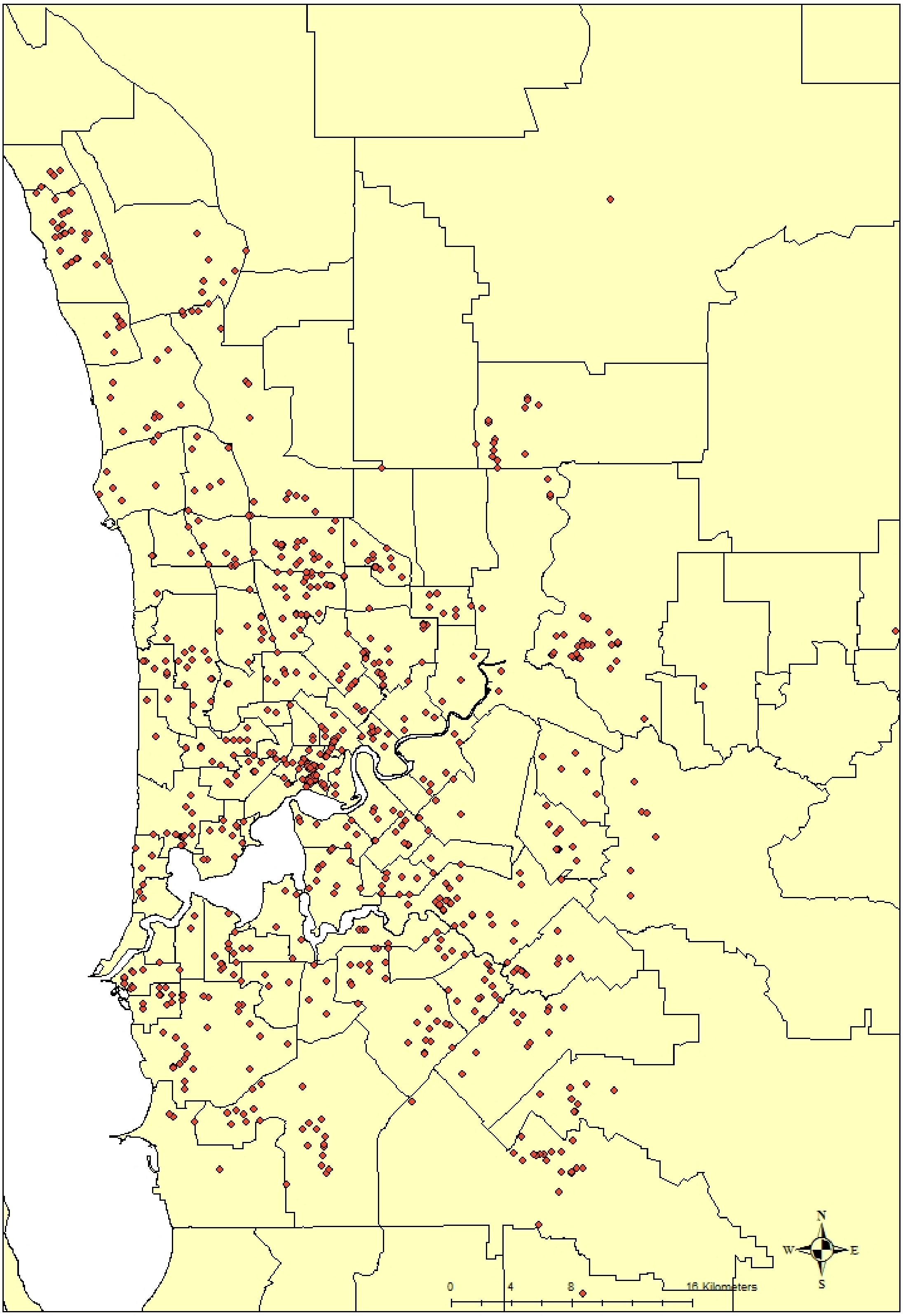
Map 1: Location of crashes involving child and adolescent pedestrians in WA between 2006 and 2016



Map 2: Location of crashes involving child and adolescent pedestrians in southern Perth between 2006 and 2016



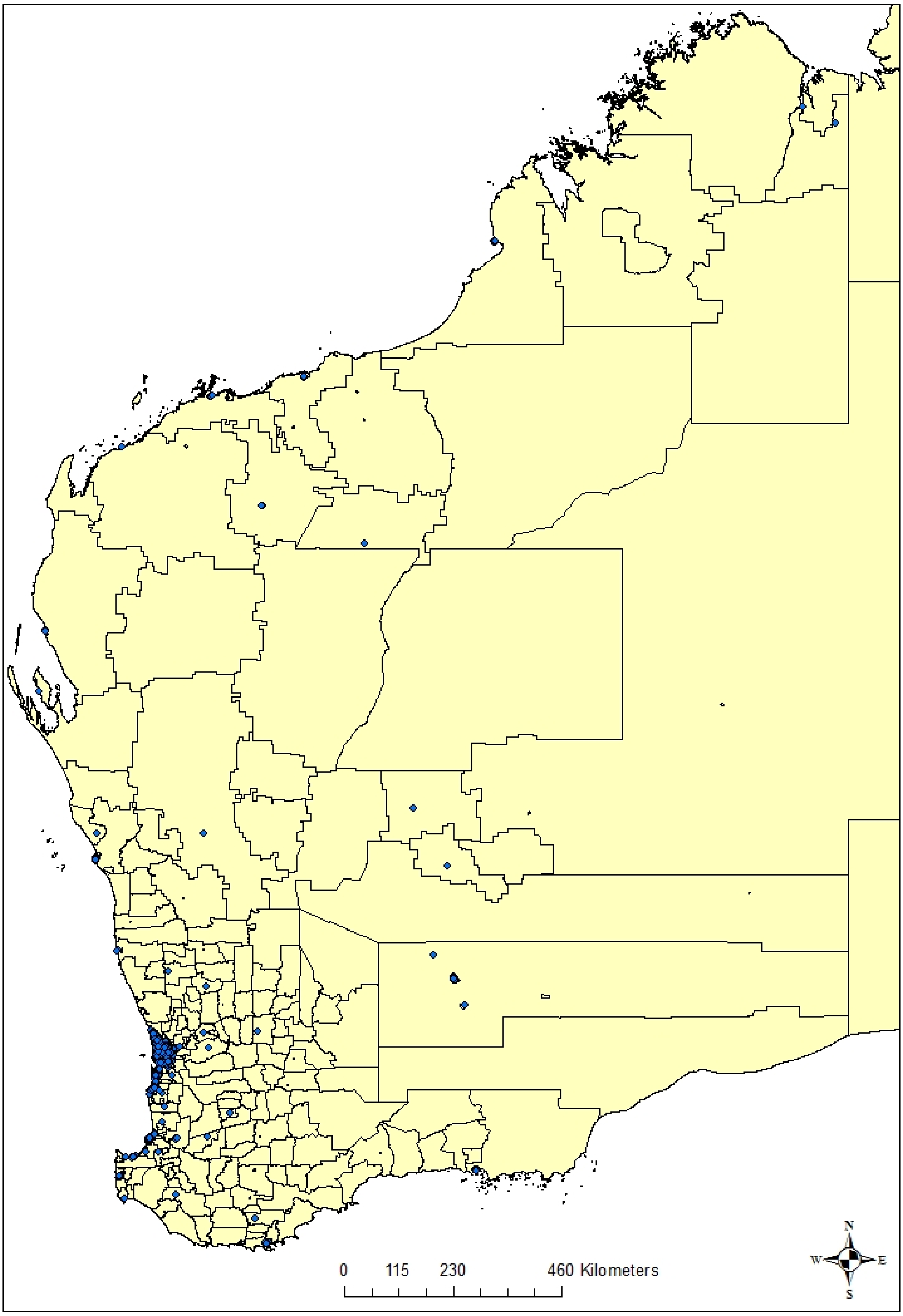
Map 3: Location of crashes involving child and adolescent pedestrians in northern Perth between 2006 and 2016



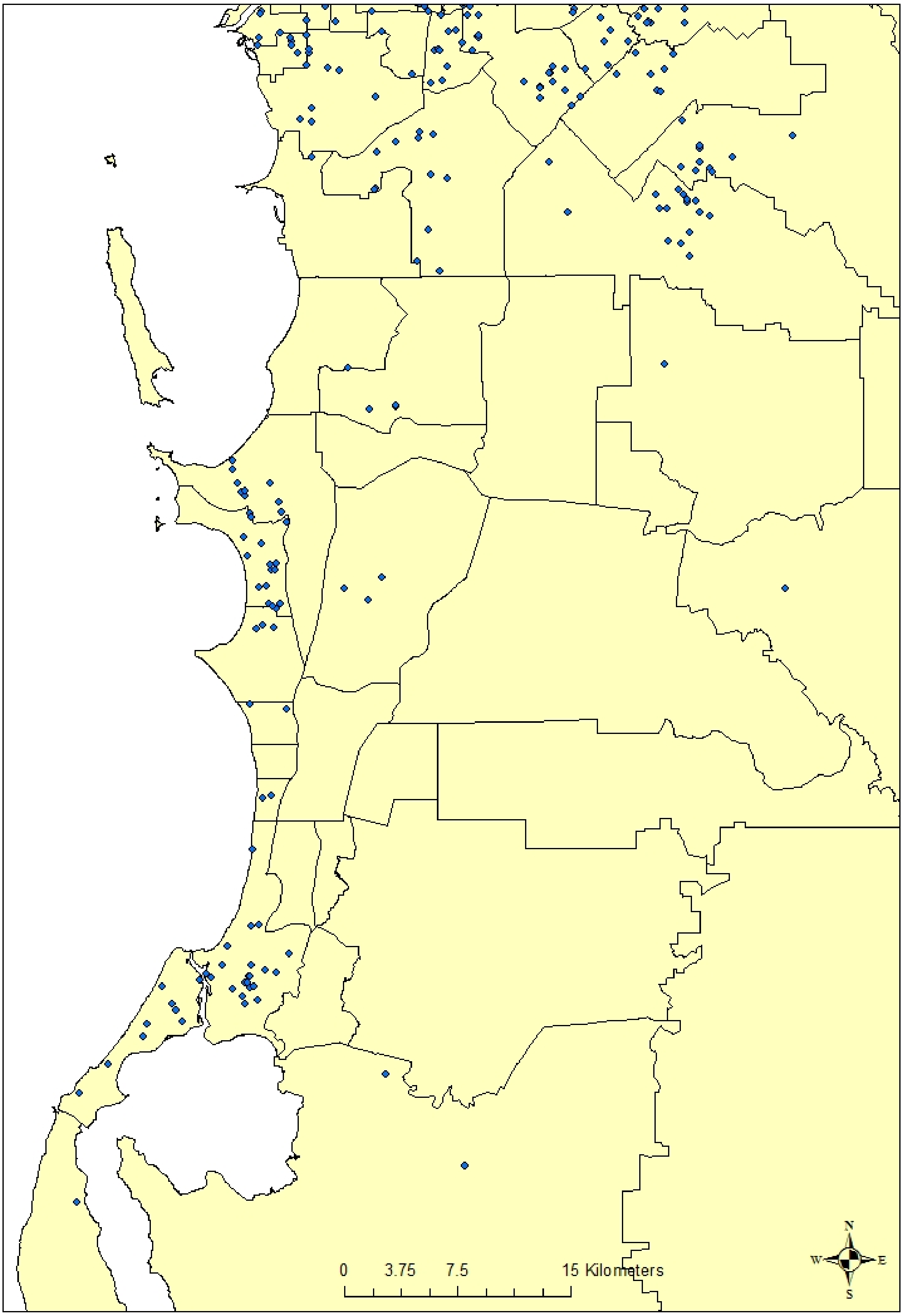
Map 4 shows the location of crashes involving child and adolescent cyclists across the state over the study period. While most of these crashes occurred in the Perth metropolitan area, several cycling crashes occurred in Kalgoorlie/Boulder, Albany, Margaret River, Collie, Bunbury and Australind, Geraldton and Karratha.

Map 5 and 6 show the locations of crashes involving child and adolescent cyclist in the Perth metropolitan area. Clusters of these crashes occurred in Mandurah, Safety Bay, Rockingham, Armadale, East Victoria Park, Scarborough, Mirrabooka, Ellenbrook, Hillarys and Joondalup, and Quinns Rocks.

Map 4: Location of crashes involving child and adolescent cyclists in WA between 2006 and 2016



Map 5: Location of crashes involving child and adolescent cyclists in southern Perth between 2006 and 2016



Map 6: Location of crashes involving child and adolescent cyclists in northern Perth between 2006 and 2016

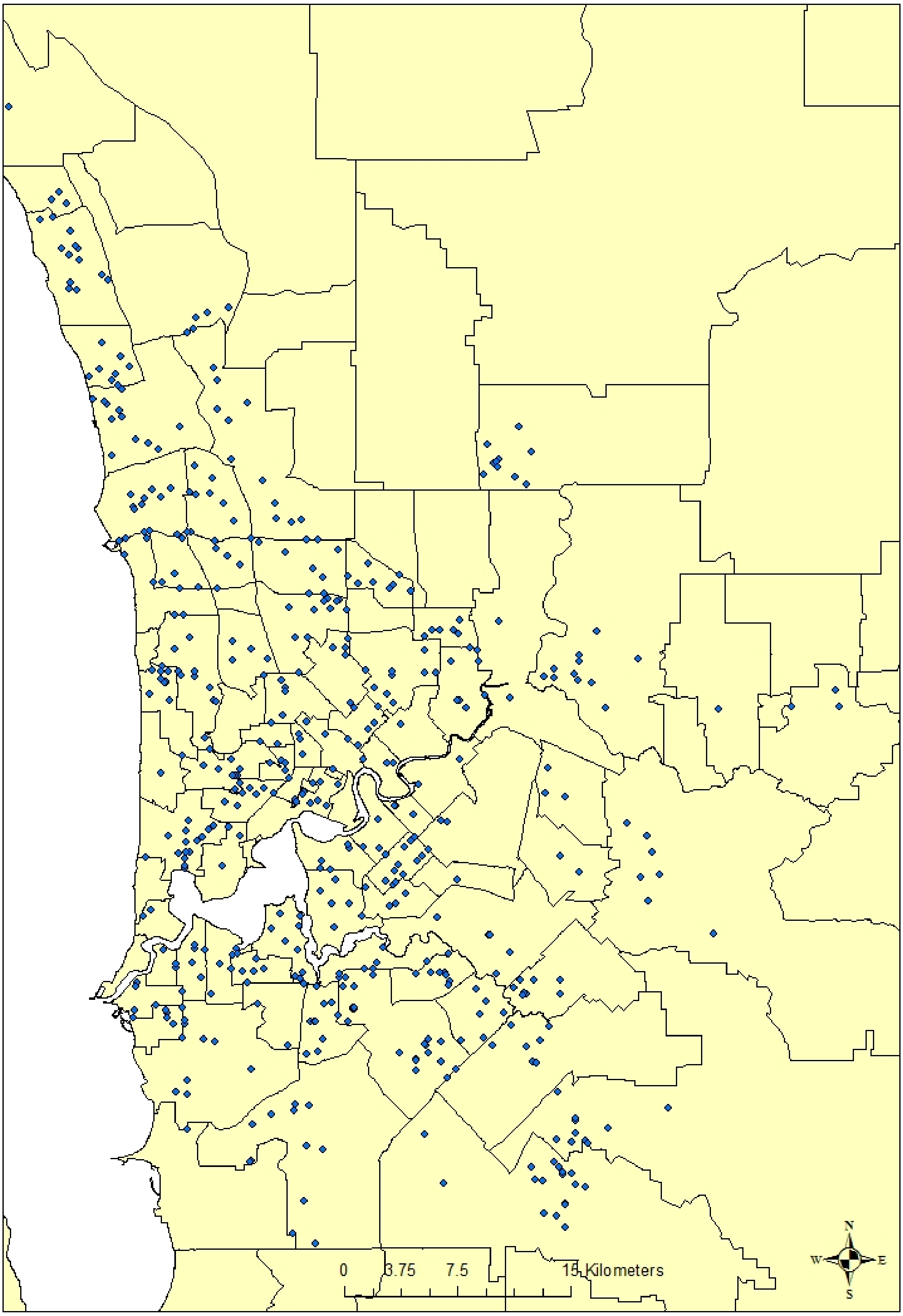


Table 4 shows the number of children and adolescents involved in each crash by year and whether the crash occurred during school zone operating hours or not from 2006 to 2016. Overall, one third of children and adolescents were involved in crashes which occurred during school zone operating hours[4], as pedestrians (n=383, 34%) and cyclists (n=298, 38%). The proportion of children and adolescents involved in crashes during school zone operating hours as pedestrians was highest in 2010 (n=50, 36%), 2011 (n=52, 37%), 2014 (n=30, 38%) and 2016 (n=31, 39%). The proportions of children and adolescents involved in crashes occurring during school zone hours as cyclists was similar, but rose in 2015 and 2016.

Table 4: Descriptive statistics of children and adolescents involved in pedestrian and cyclist crashes by school zone operating time and year in Western Australia from 2006 to 2016

School zone operating hours[1]	**Crash Year**	**2006 n (%)**	**2007 n (%)**	**2008 n (%)**	**2009 n (%)**	**2010 n (%)**	**2011 n (%)**	**2012 n (%)**	**2013 n (%)**	**2014 n (%)**	**2015 n (%)**	**2016 n (%)**
Non-school zone hours	**Child pedestrians**	62 (67)	65 (71)	87 (73)	72 (66)	88 (64)	88 (63)	88 (68)	61 (68)	48 (62)	52 (68)	48 (61)
School zone hours		30 (33)	26 (29)	32 (27)	37 (34)	50 (36)	52 (37)	41 (32)	29 (32)	30 (38)	25 (32)	31 (39)
Non-school zone hours	**Child cyclists**	65 (68)	53 (61)	48 (62)	44 (59)	47 (65)	38 (60)	44 (63)	41 (69)	33 (63)	20 (50)	33 (52)
School zone hours		30 (32)	34 (39)	30 (38)	31 (41)	25 (35)	25 (40)	26 (37)	18 (31)	19 (37)	20 (50)	31 (48)

[1]School zone operating hours: 7:30am to 9am, and 2:30pm to 4pm, from Monday to Friday during state school term-times

[4] School zone operating hours: 7:30am to 9am, and 2:30pm to 4pm, from Monday to Friday during state school term-times.

Table 5 demonstrates children and adolescents involved in crashes by type, school zone operating time and sex. A higher proportion of females were involved in pedestrian crashes during school zone operating hours than males (n=178, 38% of female pedestrian crashes, compared to n=189, 30% of male pedestrian crashes). By comparison, a lower proportion of female children and adolescents were involved in crashes as cyclists during school zone operating hours than male children and adolescents (n=43, 34% of female cyclist crashes, compared to n=238, 39% of male cyclist crashes).

Table 5: Descriptive statistics of children and adolescents involved in pedestrian and cyclist crashes by school zone operating hours and sex in Western Australia from 2006 to 2016

School zone operating hours[1]	Sex	Pedestrians n (%)	Cyclists n (%)
Non-school zone hours	**Female**	288 (62)	84 (66)
School zone hours		178 (38)	43 (34)
Total		466 (100)	127 (100)
Non-school zone hours	**Male**	438 (70)	370 (61)
School zone hours		189 (30)	238 (39)
Total		627 (100)	608 (100)

[1]School zone operating hours: 7:30am to 9am, and 2:30pm to 4pm, from Monday to Friday during state school term-times

Table 6 shows the proportion of children and adolescents involved in each crash type by occurrence during school zone operating hours or not, and the severity of a crash. A lower proportion of fatal child and adolescents crashes across pedestrian and cyclist crashes (n=5, 16% and n=2, 33% respectively) occurred during school zone operating hours compared to other times (n=26, 84% and n=4, 67% respectively). A third of child and adolescents cyclists involved in crashes and hospitalised were in crashes occurring during school zone operating hours (n=58, 33%).

Table 6: Descriptive statistics of children and adolescents involved in pedestrian and cyclist crashes by school zone operating hours and severity of crash in Western Australia from 2006 to 2016

School zone operating hours[1]	Severity	Pedestrians n (%)	Cyclists n (%)
Non-school zone hours	Fatal	26 (84)	4 (67)
School zone hours		5 (16)	2 (33)
Total		31 (100)	6 (100)
Non-school zone hours	Hospital	322 (75)	118 (67)
School zone hours		108 (25)	58 (33)
Total		430 (100)	176 (100)
Non-school zone hours	Medical	224 (63)	166 (59)
School zone hours		130 (37)	116 (41)
Total		354 (100)	282 (100)
Non-school zone hours	Property damage only	187 (57)	178 (61)
School zone hours		140 (48)	113 (39)
Total		327 (100)	291 (100)

[1]School zone operating hours: 7:30am to 9am, and 2:30pm to 4pm, from Monday to Friday during state school term-times

Figures 1 and 2 show the numbers of children and adolescents involved in a crash by severity of crash, over the study period. Figure 1 illustrates the number of child and adolescents pedestrians involved in crashes over time. There has been a drop in the number of pedestrians in crashes requiring medical treatment over time from 33 in 2006 to a low of 14 in 2015. The number of pedestrians involved in crashes with property damage only, rose to a peak of 46 crashes in 2012 and then stabilised to similar levels as 2009 (29 crashes each in 2015 and 2016). The numbers of pedestrians involved in fatal crashes or requiring hospitalisation have dropped over time to a single fatality in 2016.

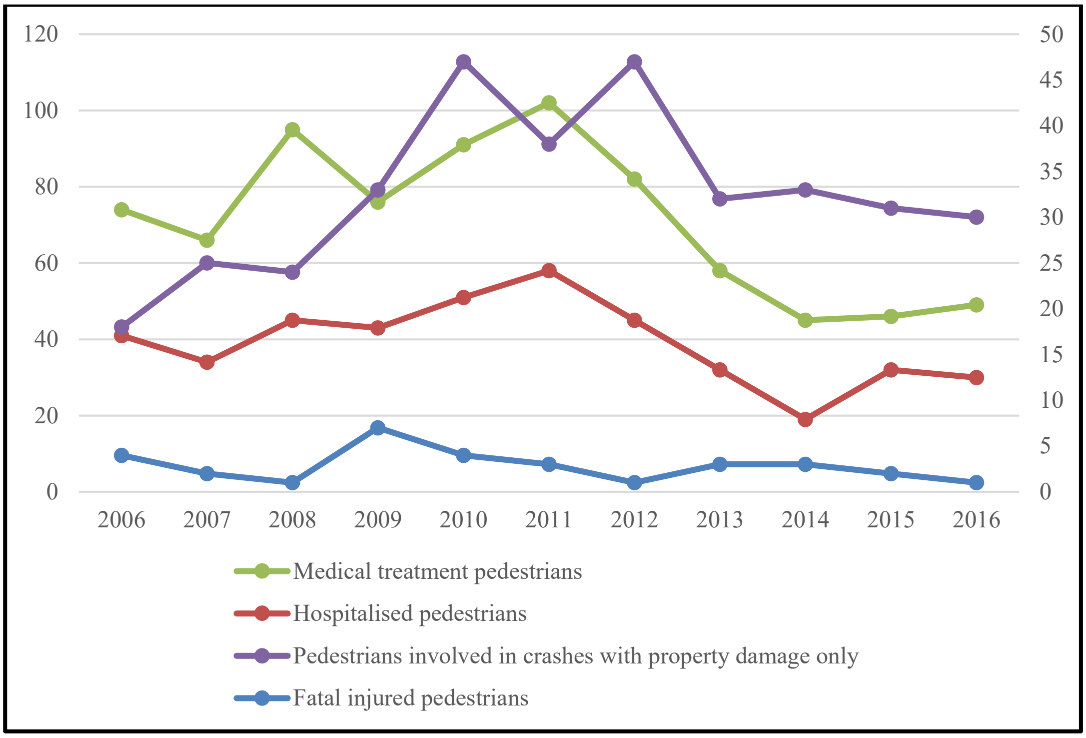


Figure 1: Child and adolescent pedestrians involved in crashes by severity of crash and year

Figure 2 illustrates severity by crashes involving child and adolescents cyclists. There were few fatalities among cyclists (two each in 2013 and 2016, and one each in 2006 and 2008). The number of cyclists involved in a crash of other severities has gradually dropped from 2006 to 2015 with increases in 2016. For example, property damage only cyclist crashes dropped from 41 in 2006 to 21 in 2015 before rising to 29 in 2016.

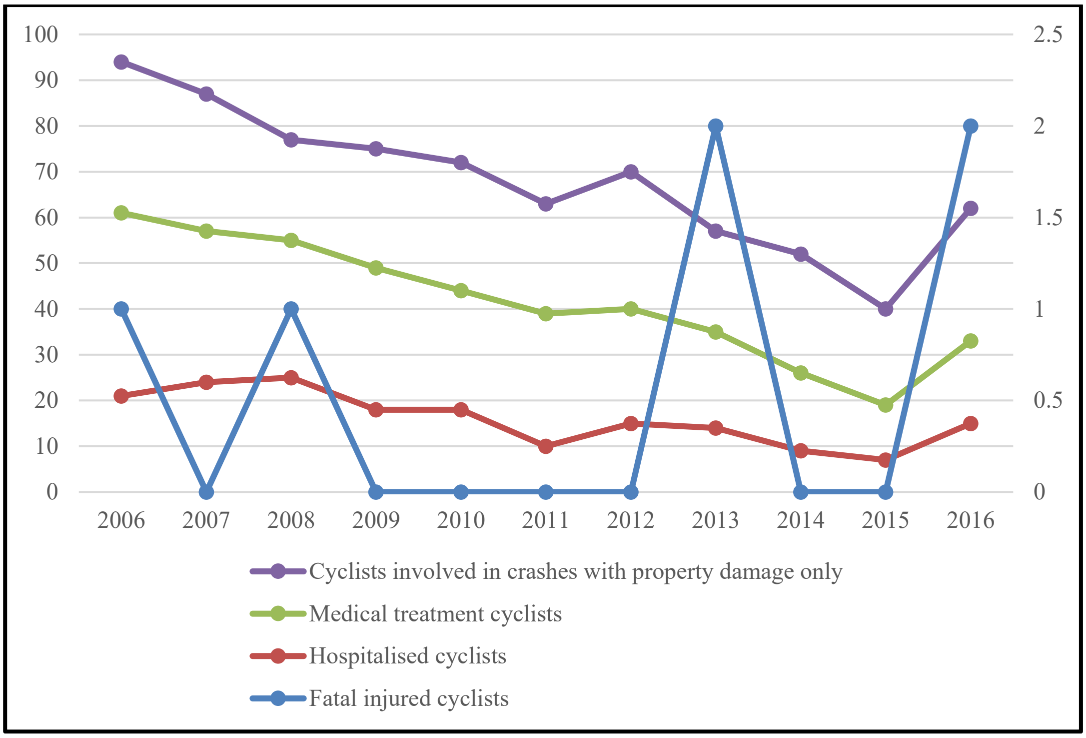


Figure 2: Child and adolescent cyclists involved in crashes by severity of crash and year

Table 7 shows the number of children and adolescents involved in crashes by crash type. More than one third of pedestrians and cyclists (n=299 and n=150 respectively) were involved in midblock crashes during school zone operating hours. A total of 40% (n=138) of cyclists were involved in crashes at intersections during school zone operating hours, with lower proportions of pedestrians (n=83, 30%) involved in these crashes during the same time period.

Table 7: Descriptive statistics of children and adolescents involved in pedestrian and cyclist crashes by school zone operating hours and crash type in Western Australia from 2006 to 2016

School zone operating hours[1]	Vehicle type	Pedestrians n (%)	Cyclists n (%)
Non-school zone hours	**Midblock**	560 (65)	251 (63)
School zone hours		299 (35)	150 (37)
Total		859 (100)	401 (100)
Non-school zone hours	**Intersection**	192 (70)	211 (60)
School zone hours		83 (30)	138 (40)
Total		275 (100)	349 (100)
Non-school zone hours	**Other**	7 (87)	4 (80)
School zone hours		1 (13)	1 (20)
Total		8 (100)	5 (100)

[1]School zone operating hours: 7:30am to 9am, and 2:30pm to 4pm, from Monday to Friday during state school term-times

Table 8 shows vehicle categories involved in child and adolescent pedestrian crashes by school zone and road user. Cyclists are excluded from this table as, by definition, 100% of cyclist crashes involve bicycles. A higher proportion of pedestrians were involved in crashes with cars and station wagons during school zone operating hours (n=39, 30%: cars, and n=215, 33%: station wagons), compared to other vehicle categories ƚ

Table 8: Descriptive statistics of children and adolescents involved in pedestrian crashes by school zone operating hours and vehicle type in Western Australia from 2006 to 2016

School zone operating hours[1]	Vehicle type	Pedestrians n (%)
Non-school zone hours	Car	91 (70)
School zone hours		39 (30)
Total		130 (100)
Non-school zone hours	Station wagon	30 (67)
School zone hours		15 (33)
Total		45 (100)
Non-school zone hours	Utility	21 (88)
School zone hours		3 (13)
Total		24 (100)
Non-school zone hours	Panel van	3 (100)
School zone hours		0 (0)
Total		3 (100)
Non-school zone hours	Truck	0 (100)
School zone hours		0 (100)
Total		0 (100)
Non-school zone hours	Bus	1 (100)
School zone hours		0 (0)
Total		1 (100)
Non-school zone hours	Motor cycle	7 (78)
School zone hours		2 (100)
Total		9 (100)
Non-school zone hours	Bicycle	1 (50)
School zone hours		1 (50)
Total		2 (100)
Non-school zone hours	Pedestrian	600 (65)
School zone hours		317 (35)
Total		917 (100)
Non-school zone hours	Four wheel drive	2 (40)
School zone hours		3 (60)
Total		5 (100)
Non-school zone hours	Other	2 (50)
School zone hours		2 (50)
Total		4 (100)

[1]School zone operating hours: 7:30am to 9am, and 2:30pm to 4pm, from Monday to Friday during state school term-times

The speed limit variable of the road where the crash occurred was only recorded in 1,617 (85%) of all 1,897 records of children and adolescents involved in crashes (Table 9). Of the recorded data, 46% (n=329) of all children involved in crashes as pedestrians were in a crash in the 50km/h speed zone, while 29% (n=223) took place in 60km/h speed zones. Nearly two-thirds (n=268) of all children involved in crashes as cyclists were in crashes in 50km/h speed zones, while 21% (n=91) occurred in 60km/hour zones.

Table 9: Descriptive statistics of children and adolescents involved in pedestrian and cyclist crashes by speed zone

Speed	Pedestrians n (%)	Cyclists n (%)
<40km/h	3 (0.40)	0 (0)
40km/h	66 (8.7)	15 (3.4)
50km/h	349 (46)	268 (61)
60km/h	223 (29)	91 (21)
70km/h	76 (10)	49 (11)
80km/h	26 (3.4)	12 (2.7)
90km/h	6 (0.79)	2 (0.46)
100km/h	3 (0.40)	1 (0.23)
110km/h	4 (0.53)	1 (0.23)
Total	756 (100)	439 (100)

Table 10 shows the number of children and adolescents involved in crashes by road user type and day of the week. The highest number of crashes involving children and adolescents occurred on Fridays (n=9,036, 17%). The lowest number of weekday crashes occurred on Mondays (n=6,717, 13%). Similar proportions of child and adolescents crashes involved pedestrians through the weekdays (approximately 15%), with a lower proportion of 13% (n=150) on Mondays. The highest proportion of child and adolescents crashes involving cyclists were on Tuesdays and Wednesdays (n=134, 18% and n=146, 19% respectively), with the lowest proportion of weekday crashes occurring on Mondays (n=101, 13%). The lowest proportion of children and adolescents involved in both cyclist and pedestrian crashes throughout the week occurred on Sundays (n=55, 7.3% and n=94, 8.2% respectively).

Table 10: Descriptive statistics of children and adolescents involved in pedestrian and cyclist crashes by day of the week

Day of the week	Pedestrians n (%)	Cyclists n (%)
Sunday	94 (8.2)	55 (7.3)
Monday	150 (13)	101 (13)
Tuesday	173 (15)	134 (18)
Wednesday	175 (15)	146 (19)
Thursday	192 (17)	110 (15)
Friday	224 (20)	118 (16)
Saturday	134 (12)	91 (12)
Total	1,142 (100)	755 (100)

Table 11 shows the number of children and adolescents involved in crashes by road user type and month of the year. The months with the highest number of children and adolescents involved in pedestrian crashes were March (n=118, 10%), May (n=111, 9.7%) and February (n=107, n=29.4%). The months with the highest number of children and adolescents involved in cycling crashes were May (n=89, 12%) and November (n=84, 11%).

Table 11: Descriptive statistics of children and adolescents involved in pedestrian and cyclist crashes by month of the year

Month of crash	Pedestrians n (%)	Cyclists n (%)
January	79 (6.9)	33 (4.4)
February	107 (9.4)	73 (9.7)
March	118 (10)	73 (9.7)
April	91 (8.0)	52 (6.9)
May	111 (9.7)	89 (12)
June	92 (8.1)	54 (7.2)
July	95 (8.3)	65 (8.6)
August	84 (7.4)	64 (8.5)
September	98 (8.6)	51 (6.8)
October	92 (8.1)	67 (8.9)
November	95 (8.3)	84 (11)
December	80 (7.0)	50 (6.6)
Total	1,142 (100)	755 (100)

4.2 Incidence rates

The incidence rates (number of child and adolescent pedestrians and cyclists involved in crashes per 100,000 population aged 17 and less) are shown below in Tables 12 to 14. Table 12 shows the incidence rates for each year included in the study. The overall incidence rate over the study period was 17.24 per 100,000 for child and adolescent pedestrians and 12.92 per 100,000 for child and adolescent cyclists. There has been a reduction in the incidence rates of child and adolescent pedestrians involved in crashes from 2006 onwards, with a large drop after 2013, followed by a rise to in 2016 to 11.30 per 100,000). The highest incidence rate of child and adolescent cyclists involved in crashes was in 2011 (24 child and adolescent cyclists per 100,000 population), with a drop in 2014 followed by an increase in 2015.

Table 12: Incidence rates of child and adolescent pedestrians and cyclists involved in crashes, per 100,000 population, in Western Australia from 2006 to 2016

Crash Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Overall
IR pedestrians	19.99	17.97	15.62	14.73	13.88	11.92	13.06	10.85	9.44	7.16	11.30	17.24
IR cyclists	17.70	16.95	22.43	19.64	22.17	24.04	21.83	16.19	9.98	14.32	13.24	12.92

[1] IR: Incidence rate (per 100,000 population)

Table 13 shows the incidence rates for each child vulnerable road user group by age and gender. Incidence rates were higher for male pedestrians and cyclists across all age groups. The difference was especially marked among male cyclists involved in crashes: incidence rates among males aged 13 to 17 years were nearly 6 times greater than among females of this age (47 per 100,000 in 13 to 17 year old males compared to 8.2 per 100,000 in 13 to 17 year old females). Incidence rates were most similar among 2 year old and under male and females, with incidence rates rising with age for both cyclists and pedestrians. These increases were greater among males than females.

Table 13 Incidence rates of child and adolescent pedestrians and cyclists involved in crashes, per 100,000 population, by age and gender, in Western Australia from 2006 to 2016

Gender	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Total
Age group	2 years or less		3 to 5 years		6 to 12 years		13 to 17 years		All ages		
IR pedestrians	3.93	4.53	9.22	14.07	9.85	16.87	31.45	35.59	14.78	19.56	17.24
IR cyclists	0.22	0.82	1.29	3.87	5.39	18.19	8.15	46.51	4.62	20.79	12.92

[1] IR: Incidence rate (per 100,000 population)

Incidence rates of child and adolescent pedestrians and cyclists involved in crashes by remoteness and school zone operating hours are indicated in Table 14 below. Incidence rates were highest in the major city area (that is, Perth metropolitan area – 20.06 child and adolescent pedestrians per 100,000 and 13.60 child and adolescent cyclists per 100,000 population). The second highest incidence rates were in the outer regional areas, where the incidence rates of child and adolescent cyclists involved in crashes were only slightly lower than in Perth (11 per 100,000 population in the outer regional areas, compared to 14 per 100,000 in Perth). The lowest incidence rates were in the very remote areas (3.0 per 100,000 population for pedestrians and 4.1 per 100,000 population for cyclists). Incidence rates for child and adolescent pedestrians in crashes during school zone operating hours were approximately half those for during non-school zone operating hours (7.1 per 100,000 and 13 per 100,000 respectively). The difference was smaller among cyclists (5.3 per 100,000 during school zone operating hours compared to 8.6 per 100,000 outside these hours).

Table 14: Incidence rates of child and adolescent pedestrians and cyclists involved in crashes, per 100,000 population, by remoteness and school zone operating hours, in Western Australia from 2006 to 2016

Remoteness	Major city	Inner regional areas	Outer regional areas	Remote areas	Very remote areas
IR[1] pedestrians	20.06	6.22	9.93	8.45	2.97
IR[1] cyclists	13.60	6.31	10.50	9.72	4.08
School zone operating hours[2]	**Non-school zone hours**	**School zone hours**			
IR[1] pedestrians	13.93	7.06			
IR[1] cyclists	8.57	5.34			

[1]IR: Incidence rate (per 100,000 population)
[2] School zone operating hours: 7:30am to 9am, and 2:30pm to 4pm, from Monday to Friday during state school term-times

4.3 Distances between crashes and schools

The median distances between crash and the closest school by sex, age and road user are shown in Table 15 below. Among children aged 2 years and under who were involved in crashes, there were greater median distances from crash to the closest school among male pedestrians (8,399m) and male cyclists (10,510m). Similarly, the highest median distance to the closest school in 3 to 5 year olds involved in crashes occurred among male cyclists (7,837m). In the 6 to 12 year old age-group, the shortest median distance from crash to the closest school was among female pedestrians (5,171m). In the 13 to 17 year old age-group, the shortest median distance from crash to closest school was among female cyclists (5,103m).

Table 15: Median distance (in metres) from child and adolescent pedestrian and cyclist crashes to the crash to the closest school, by sex and age, in Western Australia, from 2006 to 2016

Sex	Age	Pedestrians	Cyclists
Female	2 years and younger	5,520	5,390
Male		8,399	10,510
Female	3 to 5 years	5,449	5,914
Male		5,382	7,837
Female	6 to 12 years	5,171	5,790
Male		6,156	5,701
Female	13 to 17 years	5,936	5,103
Male		5,867	7,829

The median distances between crash and the closest school by sex, road user, and time of crash are shown in Table 16 below. Overall, median distances from crashes to the closest school were similar among pedestrians and cyclists outside and during school zone operating hours. Median distances were similar outside school zone operating hours among female and male child and adolescent cyclists but higher among female cyclists within school zone operating hours (5,390m). Median distance among male pedestrians and cyclists were similar within and outside school zone operating times.

Table 16: Median distance (in metres) from child and adolescent pedestrian and cyclist crashes to the closest school by sex, and whether the crash occurred during school zone operating hours, in Western Australia, from 2006 to 2016

School zone operating hours[1]	Sex	Pedestrians	Cyclists
Non-school zone hours	Female	5,622	5,006
School zone hours		5,206	5,390
Non-school zone hours	Male	6,035	5,013
School zone hours		6,059	5,052
Non-school zone	Total	5,897	5,102
School zone hours		5,889	5,141

[1]School zone operating hours: weekdays from 7:30am to 9am, and from 2:30pm to 4pm on weekdays during term-times

The median distances between crash and the closest school by severity of crash and type of road user is shown in Table 17 below. Among pedestrians, median distance to the closest school was the least among fatally injured children and adolescents (5,602m) and the most in child and adolescents pedestrians treated in hospital (6,009m). Conversely, the largest median distance to the closest school was among fatally injured child and adolescent cyclists (7,837m from crash to closest school), with hospital, medical treatment, and property damage only crashes involving cyclists tending to occur closer to the closest school (5,431m, 5,027m and 5,278m respectively).

Table 17: Median distance (in metres) from child and adolescent pedestrian and cyclist crashes to the closest school, by severity of crash, in Western Australia, from 2006 to 2016

Severity of crash	Pedestrians	Cyclists
Fatal	5,602	7,837
Hospital	6,009	5,431
Medical	5,746	5,027
Property damage only	5,886	5,278

The median distances between crash and the closest school by type of road user and remoteness is shown in Table 18 below. Median distances to the closest school were highest in the inner regional areas for all road users, particularly for cyclists (35,693m). In the outer remote area, median distance from pedestrian crashes to the closest school was the lowest median distance across remoteness area and road type – 1,607m, and more for cyclist crashes in this area (2,650m).

Table 18: Median distance (in metres) from child and adolescent pedestrian and cyclist crashes to the closest school, by remoteness area of Western Australia, from 2006 to 2016

Remoteness	Pedestrians	Cyclists
Major city	6,060	5,077
Inner regional area	22,977	35,693
Outer regional area	3,725	4,886
Inner remote area	2,301	1,788
Outer remote area	1,607	2,650

4.4 Number of pedestrian and cyclist crashes in buffer zones from the closest school

Table 19 shows the number of crashes, by vulnerable road user categories, in each buffer zone. All children under 6 years were included in a single category because of the small number of children in the 2 years and under, and 3 to 5 year categories. Only 1 crash within 500m of the closest school involved children under 6 years of age (a pedestrian), with the highest proportion of crashes in this zone occurring in primary school age children (6 to 12 years old). There were equal total numbers of children involved in crashes as cyclists and pedestrians (19 of each) within 500m of the closest school. The highest proportion of both cyclists and pedestrians involved in crashes occurred in the 13 to 17 year old groups for the larger buffer zones. These proportions were noticeably higher in the cyclist groups >500m to 2km, and >2km to 5km from crash to the closest school. Similar numbers of children involved in crashes as pedestrians and cyclists in the >2km to 5km from the closest school (pedestrians=289 and cyclists=250). The highest number of crashes occurred more than 5km from the crash to the closest school, with nearly double the number of pedestrians as cyclists (pedestrians=609 and cyclists=359).

Table 19: Number of pedestrians and cyclists involved in crashes in the buffer zones from the closest school

Distance from crash to closest school	Vulnerable road user	In buffer							
		Less than 6 years		6 to 12 years		13 to 17 years		Total	
		n	%	n	%	n	%	n	%
Up to 500m from school	Pedestrian	1	5.3	10	52.6	8	42.1	19	100
	Cyclist	0	0.0	9	47.4	10	52.6	19	100
	Total	1	2.6	19	50.0	18	47.4	38	100
>500m to 2km from school	Pedestrian	24	17.1	38	27.1	78	55.7	140	100
	Cyclist	5	6.8	20	27.0	49	66.2	74	100
	Total	23	10.8	58	27.1	127	59.4	214	100
>2km to 5km from school	Pedestrian	42	14.5	87	30.1	160	55.4	289	100
	Cyclist	6	2.4	85	34.0	159	63.6	250	100
	Total	38	7.1	172	31.9	319	59.2	539	100
>5km from school	Pedestrian	108	17.8	166	27.3	334	54.9	608	100
	Cyclist	17	4.7	138	38.4	204	56.8	359	100
	Total	80	8.3	304	31.4	538	55.6	967	100

4.5 Models

A total of four logistic models were undertaken, one for crashes occurring in each of the four buffer zones (distances from crash to the closest school of up to 500m, more than 500m and up to 2km, more than 2km and up to 5km, and more than 5km). Both pedestrian and cyclist crashes were included in each model. The results of the analyses are presented in Tables 20 to 23. The two youngest age categories (2 years old and under, and 3 to 5 years old) were collapsed into a single category, under 6 years of age, because of the relatively small number of children involved in pedestrian and cyclist crashes in these age groups.

Each model contained four sets of variables: i) individual level (age and gender of child); ii) postcode level (estimated resident population of 17 years or less, mean age of population, percentage of residents of Indigenous origin, remoteness and SEIFA or socio-economic status tertiles); iii) school level (number of students enrolled at the closest school, and crash occurring during school zone operating time); and iv) road environment factors (intersection density and traffic volume).

4.5.1 Models for crash occurring up to 500m from the closest school

Pedestrian and cyclist crashes occurring within 500m of the closest school were significantly more likely occur during the school zone operating hours (7:30am to 9am, and 2:30pm to 4pm, Monday to Friday during term-times - OR=3.287; 95% CI=1.584-6.820 – Table 20) than outside these hours. As the number of students at the closest school increased, pedestrians and cyclists were significantly more likely to occur within 500m of the school (OR=1.001; 95% CI=1.001-1.002).

Crashes occurring in postcodes with a higher population of those 17 years and under were significantly more likely to occur within 500m of the closest school but the effect size was very small (OR=1.000; 95% CI=1.000-1.000). Crashes within 500m of the closest school were significantly less likely to occur in postcode in SEIFA tertile 3 (the highest socio-economic status postcodes) than tertile 1 (the lowest socio-economic status postcodes (OR=0.252; 95% CI=0.075-0.847). Crashes within 500m of the closest school were significantly more likely to occur in postcodes in inner regional and very remote postcodes compared to metropolitan Perth (OR=3.154; 95% CI=1.061-9.380 and OR=74.693; 95% CI=7.505-748.765 respectively)

Table 20: Logistic regression model for child and adolescent pedestrians and cyclists involved in crashes occurring up to 500m from the closest school, WA, 2006-2016[#]

Predictor variables	OR[1]	95% CI[2]		p-value
Road user				
Cyclist	1.000			
Pedestrian	0.881	0.410	1.896	0.747
Gender				
Female	1.000			
Male	0.477	0.217	1.053	0.067
Age				
Under 6 years old	0.113	0.012	1.057	0.056
6 to 12 years old	1.000			
13 to 17 years old	0.708	0.338	1.482	0.359
Total students enrolled at closest school	1.001	1.001	1.002	0.000
During school zone operating time	3.287	1.584	6.820	0.001
Proportion of population of Indigenous origin	0.995	0.941	1.053	0.870
Postcode population aged 17 years of younger	1.000	1.000	1.000	0.003
Postcode level mean age	1.069	0.939	1.217	0.314
SEIFA[3] tertile 1	1.000			
SEIFA tertile 2	0.393	0.138	1.114	0.079
SEIFA tertile 3	0.252	0.075	0.847	0.026
Remoteness area				
Major city	1.000			
Inner regional	3.154	1.061	9.380	0.039
Outer regional	1.458	0.443	4.795	0.535
Remote	4.916	0.622	38.849	0.131
Very remote	74.963	7.505	748.765	0.000
Intersection density[4]	0.995	0.985	1.006	0.395
Traffic volume[5]	1.000	1.000	1.000	0.091
Crash year				
2006	1.000			
2007	1.508	0.255	8.913	0.650
2008	0.580	0.098	3.430	0.548
2009	0.274	0.026	2.874	0.280
2010	1.327	0.288	6.116	0.717
2011	0.736	0.146	3.704	0.710
2012	1.027	0.192	5.498	0.975
2013	0.198	0.018	2.232	0.190
2014	0.700	0.097	5.049	0.723
2015	0.413	0.037	4.607	0.472
2016	2.046	0.413	10.142	0.381
Constant	0.001	0.016	0.000	0.279

[1]OR: odds ratio; [2]95% CI: 95% confidence interval [3]SEIFA tertile: postcode level socio-economic status from 1 (lowest) to 3 (highest tertile) [4]Intersection density: count of intersections within 1km of the crash [5]Traffic volume: sum of AADT for all legs of the closest intersection to the crash [#]Number of observations=1,678

4.5.2 Models for crash occurring more than 500m to 2km from the closest school

Crashes occurring more than 500m to 2km from the closest school were more likely to involve pedestrians than cyclists (OR=1.639; 95% CI=1.148-2.340 – Table 20). As the number of students at the closest school increased, crashes were significantly more likely to occur more than 500m but up to 2km from the school (OR=1.001; 95% CI=1.001-1.001).

Crashes occurring in postcodes with a higher population of those 17 years and less, and higher postcode mean age were significantly more likely to occur more than 500m to 2km from the closest school (OR=1.000; 95% CI=1.000-1.000 and OR=1.133; 95% CI=1.069-1.201). Crashes more than 500m to 2km from the closest school were significantly more likely to occur in inner regional, outer regional, remote and very remote postcodes than in metropolitan Perth (OR=2.060; 95% CI=1.160-3.567, OR=2.573; 95% CI=1.427-4.636, OR=19.673; 95% CI=7.235-53.419 and OR=6.226; 95% CI=1.204-32.197 respectively).

Table 21: Logistic regression model for child and adolescent pedestrians and cyclists involved in crashes occurring >500m to 2km from the closest school, WA, 2006-2016#

Predictor variables	OR[1]	95% CI[2]		p-value
Road user				
Cyclist	1.000			
Pedestrian	1.639	1.148	2.340	0.007
Gender				
Female	1.000			
Male	1.038	0.729	1.478	0.834
Age				
under 6 years old	1.498	0.853	2.631	0.159
6 to 12 years old	1.000			
13 to 17 years old	1.285	0.881	1.873	0.193
Total students enrolled at closest school	1.001	1.000	1.001	0.000
During school zone operating time	1.065	0.756	1.500	0.718
Proportion of population of Indigenous origin	1.020	0.986	1.056	0.257
Postcode population aged 17 years of younger	1.000	1.000	1.000	0.003
Postcode level mean age	1.133	1.069	1.201	0.000
SEIFA[3] tertile 1	1.000			
SEIFA tertile 2	0.704	0.453	1.094	0.119
SEIFA tertile 3	0.667	0.413	1.077	0.098
Remoteness area				
Major city	1.000			
Inner regional	2.060	1.160	3.657	0.014
Outer regional	2.573	1.427	4.636	0.002
Remote	19.673	7.245	53.419	0.000
Very remote	6.226	1.204	32.197	0.029
Intersection density[4]	1.000	0.996	1.004	0.915
Traffic volume[5]	1.000	1.000	1.000	0.945
Crash year				
2006	1.000			
2007	0.870	0.411	1.840	0.716
2008	0.732	0.390	1.373	0.331
2009	0.569	0.292	1.110	0.098
2010	0.337	0.168	0.677	0.002
2011	0.557	0.296	1.047	0.069
2012	0.439	0.223	0.865	0.017
2013	0.549	0.275	1.095	0.089
2014	0.507	0.233	1.104	0.087
2015	0.197	0.070	0.551	0.002
2016	0.191	0.076	0.484	0.000
Constant	0.001	0.000	0.007	0.000

[1]OR: odds ratio; [2]95% CI: 95% confidence interval [3]SEIFA tertile: postcode level socio-economic status from 1 (lowest) to 3 (highest tertile) [4]Intersection density: count of intersections within 1km of the crash
[5]Traffic volume: sum of AADT for all legs of the closest intersection to the crash #Number of observations=1,678

4.5.3 Models for crash occurring more than 2km to 5km from the closest school

Pedestrian and cyclist crashes occurring more than 2km to 5km from the closest school were significantly less likely to involve pedestrians than cyclists (OR=0.691; 95% CI=0.545-0.877 – Table 21). As the number of students at the closest school increased, crashes were significantly more likely to occur more than 2km to 5km from the school (OR=1.001; 95% CI=1.001-1.001).

Crashes occurring in postcodes with a higher postcode mean age were significantly more likely to occur more than 2km to 5km from the closest school (OR=1.077; 95% CI=1.035-1.121). Crashes more than 2km to 5km from the closest school were significantly less likely to occur in postcode in SEIFA tertile 3 (highest socio-economic area) than SEIFA tertile 1 (lowest socio-economic area – OR=0.573; 95% CI=0.415-0.791). Crashes more than 2km to 5km from the closest school were significantly less likely to occur in inner regional and outer regional postcodes than in metropolitan Perth (OR=0.174; 95% CI=0.094-0.322 and OR=0.470; 95% CI=0.272-0.812 respectively).

Table 22: Logistic regression model for child and adolescent pedestrians and cyclists involved in crashes occurring >2km to 5km from the closest school, WA, from 2006-2016[#]

Predictor variables	OR[1]	95% CI[2]		p-value
Road user				
Cyclist	1.000			
Pedestrian	0.691	0.545	0.877	0.002
Gender				
Female	1.000			
Male	0.954	0.745	1.221	0.708
Age				
Under 6 years old	0.844	0.559	1.273	0.418
6 to 12 years old	1.000			
13 to 17 years old	0.921	0.716	1.183	0.518
Total students enrolled at closest school	1.001	1.001	1.001	0.000
During school zone operating time	0.976	0.771	1.235	0.841
Proportion of population of Indigenous origin	0.970	0.929	1.013	0.174
Population aged 17 years of younger	1.000	1.000	1.000	0.089
Mean age	1.077	1.035	1.121	0.000
SEIFA[3] tertile 1	1.000			
SEIFA tertile 2	0.836	0.618	1.130	0.244
SEIFA tertile 3	0.573	0.415	0.791	0.001
Remoteness area				
Major city	1.000			
Inner regional	0.174	0.094	0.322	0.000
Outer regional	0.470	0.272	0.812	0.007
Remote	1.824	0.647	5.141	0.255
Very remote	0.407	0.073	2.265	0.305
Intersection density[4]	0.998	0.996	1.001	0.163
Traffic volume[5]	1.000	1.000	1.000	0.566
Crash year				
2006	1.000			
2007	0.414	0.239	0.715	0.002
2008	0.580	0.365	0.923	0.022
2009	0.682	0.428	1.087	0.107
2010	0.476	0.300	0.755	0.002
2011	0.630	0.398	0.997	0.048
2012	0.409	0.254	0.659	0.000
2013	0.425	0.255	0.710	0.001
2014	0.265	0.147	0.480	0.000
2015	0.336	0.187	0.605	0.000
2016	0.297	0.171	0.514	0.000
Constant	0.129	0.023	0.720	0.020

[1]OR: odds ratio; [2]95% CI: 95% confidence interval [3]SEIFA tertile: postcode level socio-economic status from 1 (lowest) to 3 (highest tertile) [4]Intersection density: count of intersections within 1km of the crash [5]Traffic volume: sum of AADT for all legs of the closest intersection to the crash [#]Number of observations=1,678

4.5.4 Models for crash occurring more than 5km from the closest school

As the number of students at the closest school increased, crashes were significantly less likely to occur more than 5km from the school (OR=0.999; 95% CI=0.998-0.999 – Table 22). Crashes occurring in postcodes with a higher postcode mean age were significantly less likely to occur more than 5km from the closest school (OR=0.868; 95% CI=0.833-0.903). Crashes more than 5km from the closest school were significantly more likely to occur in postcode in SEIFA tertiles 2 and 3 than in the lowest SEIFA tertile, tertile 1 (OR=1.566; 95% CI=1.172-2.092 and OR=2.329; 95% CI=1.704-3.183 respectively). Crashes occurring in postcodes with a higher postcode mean age were significantly less likely to occur more than 5km from the closest school (OR=0.868; 95% CI=0.833-0.904). Crashes more than 5km from the closest school were significantly more likely to occur in postcode in inner regional postcodes (OR=2.348; 95% CI=1.511-3.651) and less likely to occur in remote postcodes (OR=0.031; 95% CI=0.007-0.130) than in metropolitan Perth.

Table 23: Logistic regression model for child and adolescent pedestrians and cyclists involved in crashes occurring more than 5km from the closest school, WA, 2006 to 2016[#]

Predictor variables	OR[1]	95% CI[2]		p-value
Road user				
Cyclist	1.000			
Pedestrian	1.167	0.922	1.475	0.199
Gender				
Female	1.000			
Male	1.053	0.828	1.338	0.674
Age				
Under 6 years old	1.042	0.705	1.541	0.835
6 to 12 years old	1.000			
13 to 17 years old	1.009	0.789	1.291	0.942
Total students enrolled at closest school	0.999	0.998	0.999	0.000
During school zone operating time	0.883	0.702	1.111	0.289
Proportion of population of Indigenous origin	1.007	0.970	1.046	0.705
Postcode population aged 17 years of younger	1.000	1.000	1.000	0.101
Postcode level mean age	0.868	0.833	0.904	0.000
SEIFA[3] tertile 1	1.000			
SEIFA tertile 2	1.566	1.172	2.092	0.002
SEIFA tertile 3	2.329	1.704	3.183	0.000
Remoteness area				
Major city	1.000			
Inner regional	2.348	1.511	3.651	0.000
Outer regional	1.011	0.611	1.673	0.966
Remote	0.031	0.007	0.130	0.000
Very remote	0.229	0.051	1.034	0.055
Intersection density[4]	1.001	0.998	1.003	0.557
Traffic volume[5]	1.000	1.000	1.000	0.767
Crash year				
2006	1.000			
2007	2.029	1.179	3.493	0.011
2008	1.936	1.213	3.091	0.006
2009	2.035	1.265	3.273	0.003
2010	3.185	1.996	5.083	0.000
2011	2.126	1.334	3.388	0.002
2012	3.434	2.146	5.495	0.000
2013	3.220	1.947	5.325	0.000
2014	4.819	2.757	8.423	0.000
2015	5.780	3.223	10.363	0.000
2016	5.424	3.164	9.298	0.000
Constant	89.431	15.831	505.212	0.000

[1]OR: odds ratio; [2]95% CI: 95% confidence interval [3]SEIFA tertile: postcode level socio-economic status from 1 (lowest) to 3 (highest tertile) [4]Intersection density: count of intersections within 1km of the crash [5]Traffic volume: sum of AADT for all legs of the closest intersection to the crash [#]Number of observations=1,678

5 DISCUSSION AND RECOMMENDATIONS

This study examined child and adolescent pedestrians and cyclists involved in crashes in WA, with particular reference to the proximity of the crashes relative to schools. The study investigated if the location of crashes would be affected by proximity to the closest school, and if associations differed by road user type and remoteness.

The study found that one third of all male and female cyclists and pedestrians crashes from 2006 to 2016 occurred during school zone operating hours (weekdays from 7:30am to 9am, and 2:30pm to 4pm during term-time). Although there is minimal research investigating this, it is unsurprising that many children tend to be involved in crashes during school zone operating hours, as this is the time they are exposed to traffic the most (LaScala et al., 2004, Congiu et al., 2008). The high proportion of child pedestrians and cyclists involved in crashes during school zone operating hours highlights the vulnerability of these children travelling to and from school (Schwebel et al., 2012).

Consistent with previous studies, there were higher numbers and incidence rates of male children and adolescents aged between 6 and 17 years involved in a crash as pedestrians and cyclists, possibly due to behavioural differences between male and female children including higher risk-taking by male children (Barton and Schwebel, 2007, Lin et al., 2017). The difference in numbers and incidence rates between male and female young cyclists may also be partly due to relatively more male children and adolescents cycling than females, as demonstrated in the Western Australian results of the National Cycling Participation Survey (Munro, 2017). Incidence rates rose with age for both cyclists and pedestrians, indicating probable higher independent travel levels with increasing age.

It is encouraging that the incidence rate of child and adolescent pedestrians involved in crashes has dropped from 2006 (Bramwell et al., 2014, Road Safety Commission, 2016). However, the incidence rates for child and adolescent cyclists involved in crashes was highest in 2011. Ongoing monitoring of these trends is necessary to ensure the continued safety of these vulnerable road users, as the population of WA grows and the traffic mix changes.

The highest incidence rates of child and adolescent pedestrian and cyclist crashes were in the Perth metropolitan area, followed by the outer regional areas. The lowest incidence rates were in the very remote areas. These results mirror patterns in Brisbane, Sydney and Melbourne, where total cycling and pedestrian crash incidence rates (both adult and child) were greatest in the central business districts (CBD) of these cities (Austroads Inc., 2000). The incidence rates reduced as distance from the CBD increased, and were lowest in the outer metropolitan region of these three cities (Austroads Inc., 2000). The lower incidence rates in remote WA may be the result of larger distances between amenities (such as schools, shops and recreation facilities) outside major cities and towns, reducing the amount of walking and cycling, especially among children. Regional and remote areas are also likely to have lower motor vehicle congestion leading to less risk to pedestrians and cyclists.

An interesting finding from the study was that the median distances from cyclist and pedestrian crashes to closest school were larger for crashes which occurred during school zone operating hours than outside these hours. This suggests that many of child and adolescent crashes occurring shortly before and after school hours are not occurring close to schools.

Overall, the median distances from crash to the closest school were between 5 km and just over 6km for most child and adolescent pedestrians and cyclists in the study. School zones are located immediately adjacent to schools: the Main Roads guidelines recommend a minimum length of 200m where the school zone speed limit is 40km/h and 300m when the school zone speed limit is 60km/h (Main Roads Western Australia, 2014). It is clear that a high proportion of crashes involving children occur some distance from the closest school, and well outside the school zone of that school. Since school-aged children are clustered in and around schools for several hours of the day, traffic safety efforts close to schools, including the time-based speed limits around schools and education programs on safety around schools, may be appropriate and effective at current volumes of child pedestrian and cyclist traffic in Perth.

The median distances between crashes and the closest school were much larger in inner regional areas, than in the Perth metropolitan area, outer regional and remote areas. This is despite only slightly higher proportions of pedestrian and cyclists crashes by population size in inner regional, compared to the metropolitan, areas. This may have been the result of differences in the number and location of schools, relative to the road network, compared to the metropolitan area and more remote areas.

The median distances between crashes and the closest school in outer regional, and remote and very remote areas were considerably smaller for child and adolescent pedestrian and cyclist crashes, compared to the metropolitan area, although previous research has shown that median distances from home to school in regional and remote areas are higher than in urban areas (Carver et al., 2013). This suggests a closer relationship between school location and crash location, in remote and very remote areas. Alterations to the size of the school zone, timing and marking of school zones may need to be adjusted in these areas.

Crashes involving child and adolescent pedestrians and cyclists within 500m of the closest school were significantly more likely to occur during school zone operating hours. The higher numbers of children travelling on foot or by bicycle during this time close to school (travelling to and from school) may be driving this association. This explanation is supported by the finding that, as school enrolment numbers go up, pedestrian and cyclist crashes are more likely to occur within 500m of the closest school. Given that the number of children involved in crashes in this zone (38 children and adolescents over 11 years) is relatively small compared to crash numbers further from schools, school zones appear to be operating effectively.

Crashes were more likely to involve child and adolescent pedestrians between 500m and 2km from the closest school, and more likely to involve child and adolescent cyclists between 2km and 5km from the closest school. The higher pedestrian involvement between 500m and 2km is probably related to the distances commonly walked by children and adolescents who engage in active transportation to school as a pedestrian. A survey in Perth found that children live on average 1.7km from school (Trapp et al., 2011) while a survey in Melbourne found that children are more likely to actively commute to school if they have to travel less than 800 metres in each direction (Timperio et al., 2006). Children and adolescents who cycle are likely to travel further, because of the greater speed and lower energy expenditure per unit distance travelled when cycling compared to walking. This increased exposure may explain the higher odds of a crash for cyclists between 2km and 5km from the closest schools.

Children and adolescent pedestrians and cyclists were more likely to be involved in crashes up to 2km from the closest school in regional and remote areas compared to the metropolitan area, possibly due to factors such as less signage in and near school zone areas, reduced compliance by drivers or enforcement of speed limits in school zone areas, and higher speed roads near schools, compared to Perth. Crash risk beyond 2km from the closest school varies, depending on level of remoteness. This may be related to differences in the road network between remoteness areas, especially relating to school location, and differing patterns of travel by children and adolescents across the state.

As the postcode mean age goes up, child and adolescent pedestrian and cyclist crashes were more likely to occur between 500m and 5km from the closest school. It is unclear why this is the case and there is no previous research with similar findings. The higher postcode mean age may point to older drivers, and reduced awareness of school children and adolescents, because there may be less children in the neighbourhood. Many older residents may no longer have school-age children or adolescents themselves.

Crashes occurring up to 500m, and between 2km and 5km of the closest school were less likely to occur in postcodes in higher SEIFA tertiles. Results from surveys in Australia, Sweden, Iran and the US have shown that children and adolescents with lower household incomes are more likely to actively travel to school (Spallek et al., 2006, Johansson et al., 2012, Shokoohi et al., 2012, McDonald, 2008, Babey et al., 2009). This suggests that more children residing in lower SEIFA postcodes may be walking and cycling to and from school. Distances to the local public school are likely to be under 5km in Perth, where 40% of crashes involving child and adolescent pedestrians and 49% of crashes involving child and adolescent cyclists in Perth occurred during the study period. Regularly travelling longer distances to school (more than 1.6km) has been associated with injury (Gropp et al., 2013), potentially explaining the increased crash risk in lower socio-economic status postcodes between 2km to 5km from the closest school. There may also be less protective measures in place (such as cycling paths, safer intersections and pedestrian crossovers) in local roads in lower socio-economic areas due to funding constraints (Main Roads Western Australia, 2018). Child and adolescent pedestrians and cyclists living in higher socio-economic status postcodes were more likely to be injured in areas further than 5km from the school. Schools in higher socio-economic status postcodes may have access to more targeted education and teaching from these schools compared to postcodes of lower socio-economic status.

5.1 Strengths and limitations

This study was strengthened by the use of eleven years of data, meaning that the results were not affected by individual years with, for example, a very high or low number of child pedestrian or cyclist crashes. Further, the use of multiple years of data increased the power of the statistical models. In addition, every reported pedestrian and cyclist crash in Western

Australia which involved children and adolescents aged under 18 years from 2006 to 2016 was included in the study.

The location of crashes was available and almost every school could be located. However, the residential location of each child involved in a crash was not available and the school closest to the crash was not necessarily the school attended by the child involved in the crash.

Traffic volume data was not available for each crash site, so AADT was used from the closest intersection. Within the metropolitan area and larger regional towns, this was likely to be a relatively accurate measure of traffic volume; however, in much of regional and remote WA, it would be less accurate as there are fewer intersections per unit area (as indicated in the Main Roads intersection shapefile).

Issues with the crash data from 2014 onwards may have affected the results. There was reduction in the overall number of crashes reported during and particularly after 2014, despite large increases in Perth's population over the study period. Changes in reporting and coding procedures may have contributed to this reduction, and that this varied across the crash dataset. These issues have been noted in other projects and are currently being investigated further. The results from 2014 onwards may be an underestimate due to issues with the data.

Less serious crashes, especially those leading to minor injuries or property damage only crashes, are less likely to be reported to the police, which may lead to underestimation of these crashes. Previous research has indicated that cycling crashes are frequently not reported to the police (Austroads Inc., 2000, Wegman et al., 2012), reducing the power of the models and possibly failing to demonstrate true associations with child cyclist crashes.

5.2 Recommendations

"Toward Zero", the Western Australian road safety strategy for 2008 to 2020, identifies pedestrians and bicyclists as high priority categories which can benefit from interventions involving all four cornerstones of the Safe Systems road safety approach – '*safe road use(rs)*', '*safe road and roadside*', '*safe speeds*' and '*safe vehicles*' (Office of Road Safety, 2009). The following recommendations use these cornerstones as their basis:

1. *Maintain high levels of protection, including school crossing supervisors, speed limits and enhanced signage, within school zones and up to 500m from schools, during the hours before and after school*

As the transport and public health systems increasingly promote active transportation, safety measures around schools may need to be adjusted accordingly as volumes of children and adolescent pedestrians and cyclists increase over time.

2. *The size of school zones may need to be reconsidered in regional and remote Australia*

School zones range in length from approximately 200m to 300m from the closest school, depending on the speed limit of the specific school zone (Main Roads Western Australia, 2014). However, crash risk among child and adolescent pedestrians and cyclists is higher in regional and remote areas than in Perth up to 2km from the closest school. Thus government is encouraged to consider the application of the existing guidelines relevant to regional and remote WA and the merit of these in fully achieving the school zone policy intent. The size of schools zones in regional and remote areas may need to be adjusted accordingly. Optimal signage of school zones needs to be continued and evaluated. For example, the program replacing static signs with electronic school zones signage across WA, funded by the Road Trauma Trust Account (Main Roads Western Australia, 2014), has aimed to improve the visibility of these zones, and thereby the safety of school children.

3. *Implement interventions to protect child and adolescent pedestrians and cyclists in areas beyond school zones with high volumes of pedestrians and cyclists*

Given that 96% of these crashes occurred beyond 500m from the closest school, interventions are also needed for non-school times and other locations (Rothman et al., 2015).

4. *Interventions should be tailored to the specific mix of child and adolescent pedestrian and cyclist traffic, and the socio-demographic profile of the area*

Changes relating to the '*safe roads and roadsides*' cornerstone of the Safe Systems approach are relevant in reducing crash risk to child and adolescent pedestrians and cyclists. Improved visibility is vital, specifically at intersections and crossings, for both child cyclists and pedestrians, especially because of their smaller size. Infrastructure changes can improve safety for these children in high risk areas. Marked crossings and speed cushions located further from these crossings improves drivers' yielding to these road users (Leden et al., 2006). Higher speed crashes involving pedestrians lead to higher injury severity. Therefore, reducing speeds in areas with high volumes of child and adolescent pedestrians and cyclists, for example, parks and recreational facilities, should be considered. In addition, the separation of vulnerable road users from traffic is an effective method to improve safety. This could include construction of pedestrian bridges or underpasses over large roads, footpaths, shared paths with dividing lines and dedicated cycle lanes. However, these changes need to be tailored to the needs of specific neighbourhoods, including the schools in the area (primary versus secondary), socio-economic status of the area and age distribution of the overall population (for example, higher number of very young children, or older drivers). The areas with high numbers of young pedestrians may have different infrastructure requirements to areas with high number of young cyclists, and this should be taken into account when choosing appropriate infrastructure improvements.

5. *Continue to fund programs to educate and build road safety skills of school-aged pedestrians and cyclists*

Although it is concerning that children and adolescents continue to be involved in crashes as pedestrians and cyclists, this study has shown that the absolute number of crashes is relatively low, especially close to schools. This is no doubt partly due to the education programs provided to school children in WA (relating to the '*safe road use(rs)*' cornerstone of the Safe System approach. SDERA (SDERA, 2017) provides road safety training and resources for both primary and secondary school-aged children. This includes training of educators (for example, the Smart Steps program for children under 8 years and the Challenges and Choices program – which includes road safety education - for primary school-aged children). The RAC hosts primary school incursions and secondary school programs educating about road safety. These vital programs should be continued and funded as appropriate.

6. *Encourage and enforce the use of cycling helmets among child and adolescent cyclists.*

Unfortunately, data on cycling helmet use is not available in the IRIS. However, with a goal of zero serious and fatal injuries from road trauma, the use of cycling helmets to protect children and adolescents is vitally important. New South Wales research (Olivier et al., 2013) and a Cochrane review (Macpherson and Spinks, 2008) indicating sustained reductions in numbers of head injuries for cyclists and significant increases in helmet use after mandatory helmet legislation. The enforcement of the correct use of cycling helmet use is essential among younger children especially, as their brains continue to grow and develop.

7. *Additional sources of data about cycling crashes should be explored for use in future studies. Addition data specific to pedestrians and cyclists should be collected in police crash reports.*

It has been noted that research into cycling crashes is hampered by low reporting of these crashes to police, compared to reporting of crashes involving other road users. Data on additional details relevant to cyclists, such as helmet use, should be reported in the IRIS.. Future research should include collecting data on cycling crashes using sources which are complementary to police reports (Wegman et al., 2012) such as Emergency Department and hospital records which provides additional information related to the injury, type and severity.

8. *Additional studies need to further explore the impact of area level socio-economic status on child and adolescent pedestrian and cyclist crashes*

The impact of socio-economic status on crash risk varies according to distance from a school. The effects of both individual level and area level socio-economic status on crash risk to child and adolescent pedestrians and cyclists need to be examined further to provide more detailed results. For example, combining survey data on individual level socio-economic data with crash data could give more information on the relationship between crash risk and socio-economic status. A qualitative study could explore the underlying mechanisms in the relationship between crash risk and socio-economic status

5.3 Conclusion

This study examined child and adolescent pedestrians and cyclists involved in crashes, and found that the odds of crash differed by distance from the closest school, crash type, time of crash, remoteness and neighbourhood socio-economic status.

Department of Transport initiatives such as YourMove and public health advocates are increasingly promoting active transportation, including to schools, among all West Australians. Studies have shown that replacing short car trips with cycling would lead to improved population level health (primarily through improved air quality), leading to lower mortality and health care costs, and improved physical fitness (Grabow et al., 2012, Stevenson et al., 2016). However, increases in the cumulative distance travelled by pedestrians and cyclists will lead to increases in crashes and injuries involving these road users unless changes to speed and infrastructure are made to reduce conflicts with other road users (Wegman et al., 2012). The WA's Cycling Network Plan (Department of Transport Western Australia and Main Roads

Western Australia, 2016) sets out to develop guidelines and potential cycling routes to develop Perth into a "*...great cycling city...*", which is safe for cyclists *"...of all ages..."*. The plan mentions safety as a priority and the importance of access to schools and parks, as well as routes incorporating shared paths and low speed (30k/h) roads. The realisation of these goals, and accommodation of pedestrian needs in the road network, both in Perth and in the rest of WA, is vital to encourage safe active transport and recreational travel for child and adolescent pedestrians and cyclists.

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7 APPENDIX

7.1 SEIFA definition

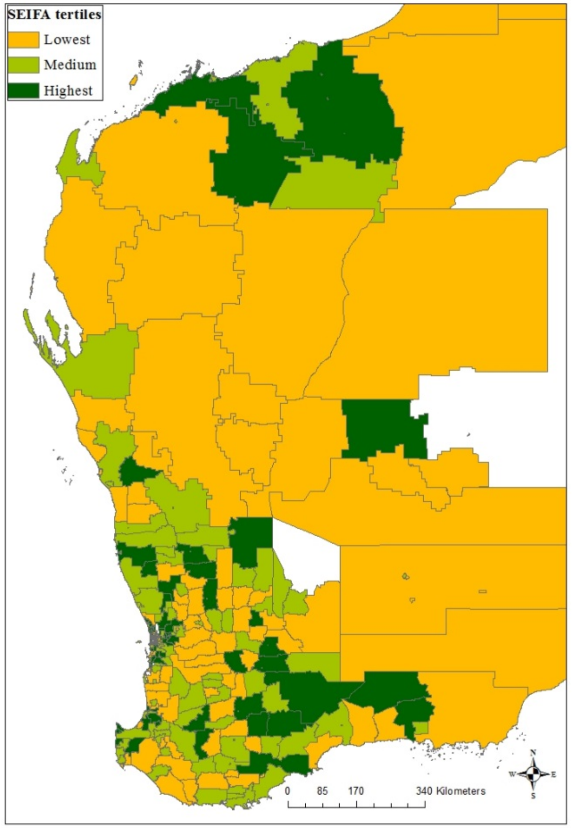
SEIFA or the Socio-economic Indexes for Areas consist of indexes of relative advantage, disadvantage, economic resources, and education and occupation, which are constructed by the Australian Bureau of Statistics (ABS). This study used the Index of Relative Socio-economic Advantage and Disadvantage (IRSAD) at postcode level. A low score indicated most disadvantaged postcodes. The lowest tertile (tertile 1) is therefore the postcodes with the lowest one-third of scores in WA. The highest tertile (tertile 3) contains postcodes with the highest one-third of scores in WA.

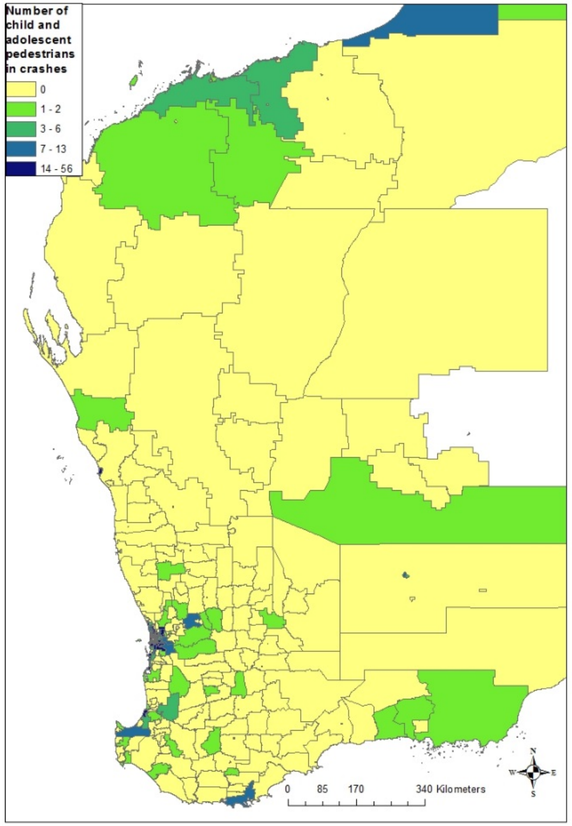
The index uses a combination of variables relating to income, education level, employment status, type of employment, mortgage/rent cost, size of private houses and dependent people in households. The SEIFA index used in the study contained the following variables in 2011:

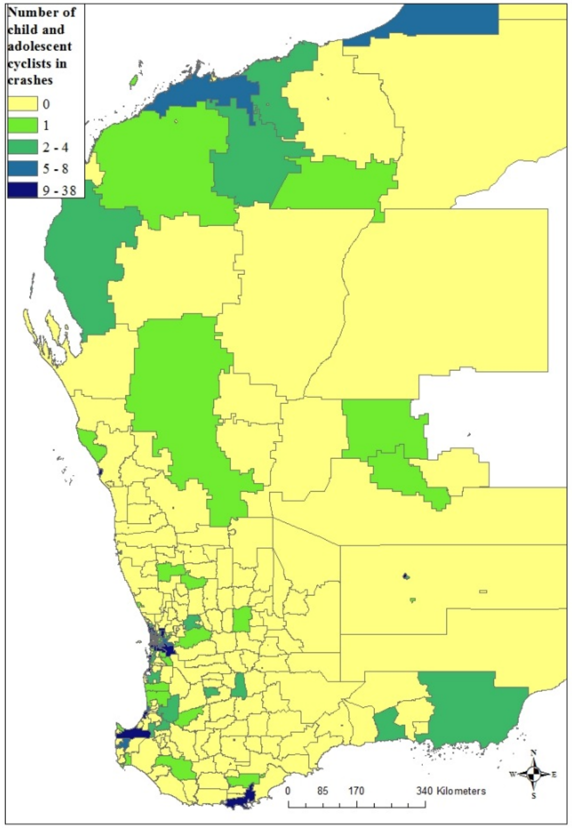
Description	Loading
% of people with stated household equivalised income greater than $52,000 per year	0.84
% of occupied private dwellings paying mortgage greater than $2,800 per month	0.7
% of people aged 15 years and over whose highest level of educational attainment is a diploma qualification	0.63
% of employed people classified as Professionals	0.62
% of occupied private dwellings with four (4) or more bedrooms	0.52
% of employed people classified as managers	0.42
% of occupied private dwellings paying rent greater than $370 per week	0.4
% of occupied private dwellings with one or more spare bedrooms	0.37
% of people aged 15 years and over at university or other tertiary institution	0.36
% of occupied private dwellings with three (3) or more cars	0.35
% of people aged 15 years and over who have no educational attainment	-0.37
% of occupied private dwellings requiring one or more extra bedrooms	-0.45
% of occupied private dwellings with no cars	-0.49
% of employed people classified as low skill Community and Personal Service workers	-0.51
% of employed people classified as Machinery Operators and Drivers	-0.57
% of people aged 15 years and over who are separated or divorced	-0.57
% of occupied private dwellings paying rent less than $166 per week (excluding $0 per week)	-0.67
% of people under the age of 70 who have a long-term health condition or disability and need assistance with core activities	-0.67
% of people (in the labour force) who are unemployed	-0.69
% of one parent families with dependent offspring only	-0.69
% of employed people classified as Labourers	-0.78
% of families with children under 15 years of age who live with jobless parents	-0.8
% of people aged 15 years and over whose highest level of education is Year 11 or lower	-0.82
% of occupied private dwellings with no internet connection	-0.82
% of people with stated household equivalised income between $1 and $20,799 per year	-0.8

Source: 2033.0.55.001 - Census of Population and Housing: Socio-Economic Indexes for Areas (SEIFA), Australia, 2011
http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/2033.0.55.001main+features100042011

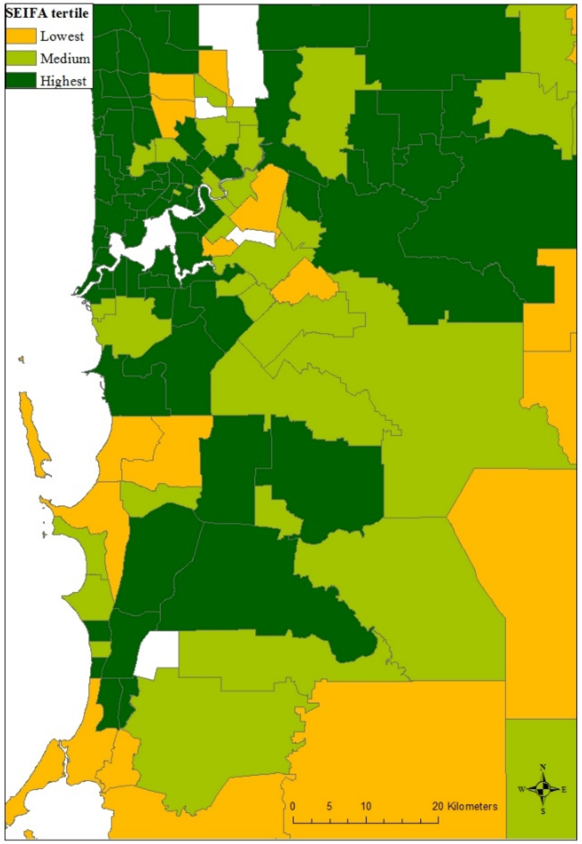
Map 7: Western Australian postcodes, by postcode-level socio-economic status (SEIFA) tertiles (left), number of child and adolescent pedestrians involved in crashes (middle) and number of child and adolescent cyclists involved in crashes, from 2006 to 2016

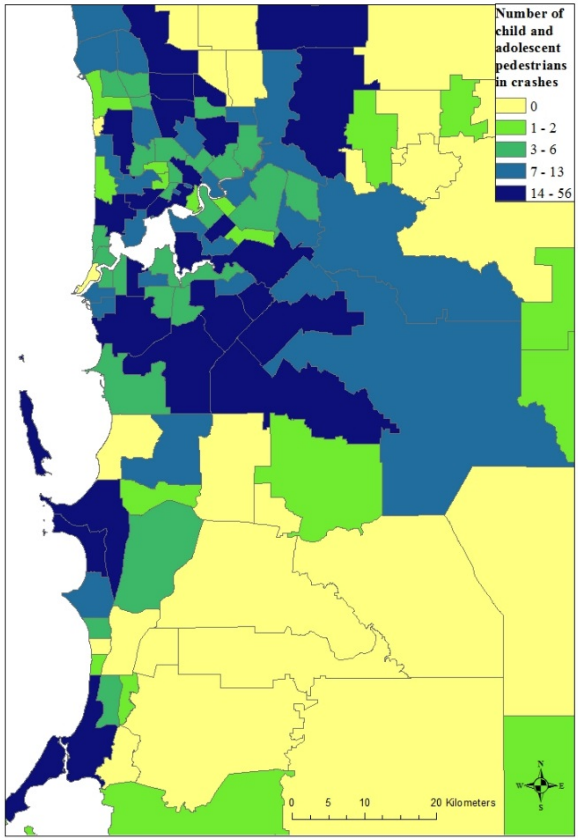






Map 8: Perth postcodes by postcode-level socio-economic status (SEIFA) tertiles (left), number of child and adolescent pedestrians involved in crashes (middle) and number of child and adolescent cyclists involved in crashes, from 2006 to 2016





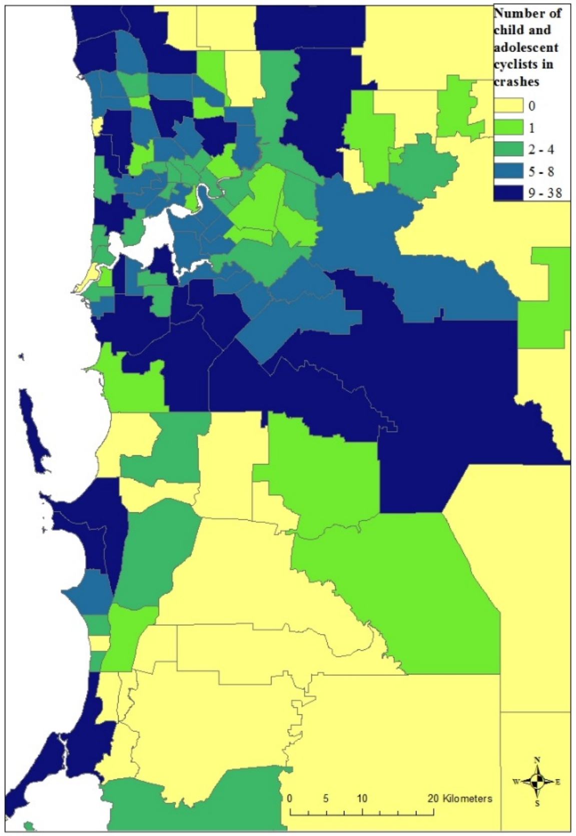


Table 24: Logistic regression model for child and adolescent pedestrians and cyclists involved in crashes occurring up to 200m from the closest school, WA, 2006-2016

Predictor variables	OR[1]	95% CI[2]		p-value
Road user				
Cyclist	1.000			
Pedestrian	2.367	0.765	7.319	0.135
Gender				
Female	1.000			
Male	0.714	0.228	2.239	0.564
Age				
Under 6 years old	Empty			
6 to 12 years old	1.000			
13 to 17 years old	0.683	0.248	1.884	0.462
Total students enrolled at closest school	1.001	1.000	1.002	0.025
During school zone operating time	4.669	1.548	14.085	0.006
Proportion of population of Indigenous origin	0.838	0.621	1.131	0.249
Postcode population aged 17 years of younger	1.000	1.000	1.000	0.051
Postcode level mean age	1.074	0.873	1.322	0.500
SEIFA[3] tertile 1	1.000			
SEIFA tertile 2	0.422	0.099	1.794	0.243
SEIFA tertile 3	0.147	0.022	1.004	0.050
Remoteness area				
Major city	1.000			
Inner regional	4.063	0.962	17.164	0.057
Outer regional	3.967	0.536	29.383	0.177
Remote	24.997	1.371	455.699	0.030
Very remote	Empty			
Intersection density[4]	1.001	0.987	1.014	0.925
Traffic volume[5]	1.000	1.000	1.000	0.288
Crash year				
2006	1.000			
2007	1.353	0.133	13.774	0.798
2008	0.256	0.020	3.247	0.293
2009	Empty			
2010	0.624	0.089	4.354	0.634
2011	0.209	0.017	2.636	0.226
2012	0.576	0.067	4.943	0.615
2013	0.242	0.017	3.421	0.294
2014	0.404	0.030	5.414	0.494
2015	Empty			
2016	2.000	0.301	13.290	0.473
Constant	0.000	0.000	2.160	0.073

[1]OR: odds ratio; [2]95% CI: 95% confidence interval [3]SEIFA tertile: postcode level socio-economic status from 1 (lowest) to 3 (highest tertile) [4]Intersection density: count of intersections within 1km of the crash [5]Traffic volume: sum of AADT for all legs of the closest intersection to the crash

Table 25: Logistic regression model for child and adolescent pedestrians and cyclists involved in crashes occurring >200m to 2km from the closest school, WA, 2006-2016

Predictor variables	OR[1]	95% CI[2]		p-value
Road user				
Cyclist	1.000			
Pedestrian	1.413	1.004	1.989	0.048
Gender				
Female	1.000			
Male	0.933	0.663	1.313	0.689
Age				
Under 6 years old	1.338	0.769	2.330	0.303
6 to 12 years old	1.000			
13 to 17 years old	1.230	0.857	1.764	0.261
Total students enrolled at closest school	1.001	1.001	1.001	0.000
During school zone operating time	1.137	0.818	1.580	0.446
Proportion of population of Indigenous origin	1.022	0.988	1.058	0.213
Postcode population aged 17 years of younger	1.000	1.000	1.000	0.001
Postcode level mean age	1.129	1.067	1.195	0.000
SEIFA[3] tertile 1	1.000			
SEIFA tertile 2	0.662	0.432	1.015	0.058
SEIFA tertile 3	0.636	0.400	1.013	0.056
Remoteness area				
Major city	1.000			
Inner regional	2.096	1.206	3.644	0.009
Outer regional	2.511	1.419	4.444	0.002
Remote	17.967	6.691	48.244	0.000
Very remote	14.602	3.331	64.009	0.000
Intersection density[4]	1.000	0.996	1.003	0.878
Traffic volume[5]	1.000	1.000	1.000	0.782
Crash year				
2006	1.000			
2007	0.918	0.441	1.913	0.820
2008	0.763	0.409	1.420	0.393
2009	0.582	0.301	1.125	0.107
2010	0.394	0.202	0.769	0.006
2011	0.615	0.332	1.138	0.121
2012	0.464	0.238	0.904	0.024
2013	0.512	0.256	1.023	0.058
2014	0.529	0.247	1.134	0.102
2015	0.229	0.087	0.602	0.003
2016	0.208	0.085	0.507	0.001
Constant	0.001	0.000	0.010	0.000

[1]OR: odds ratio; [2]95% CI: 95% confidence interval [3]SEIFA tertile: postcode level socio-economic status from 1 (lowest) to 3 (highest tertile) [4]Intersection density: count of intersections within 1km of the crash [5]Traffic volume: sum of AADT for all legs of the closest intersection to the crash

Table 26: Logistic regression model for child and adolescent pedestrians and cyclists involved in crashes occurring up to 300m from the closest school, WA, 2006-2016

Predictor variables	OR[1]	95% CI[2]		p-value
Road user				
Cyclist	1.000			
Pedestrian	1.532	0.604	3.880	0.369
Gender				
Female	1.000			
Male	0.582	0.223	1.519	0.269
Age				
Under 6 years old	Empty			
6 to 12 years old	1.000			
13 to 17 years old	0.810	0.341	1.927	0.634
Total students enrolled at closest school	1.001	1.000	1.002	0.004
During school zone operating time	3.755	1.543	9.141	0.004
Proportion of population of Indigenous origin	0.882	0.744	1.046	0.149
Postcode population aged 17 years of younger	1.000	1.000	1.000	0.001
Postcode level mean age	1.090	0.929	1.279	0.291
SEIFA[3] tertile 1	1.000			
SEIFA tertile 2	0.515	0.150	1.767	0.291
SEIFA tertile 3	0.166	0.035	0.794	0.025
Remoteness area				
Major city	1.000			
Inner regional	2.655	0.711	9.917	0.147
Outer regional	2.671	0.545	13.094	0.226
Remote	47.614	4.596	493.294	0.001
Very remote	401.290	16.144	9974.899	0.000
Intersection density[4]	0.998	0.986	1.010	0.722
Traffic volume[5]	1.000	1.000	1.000	0.108
Crash year				
2006	1.000			
2007	1.685	0.192	14.827	0.638
2008	0.626	0.070	5.621	0.676
2009	0.390	0.030	5.034	0.470
2010	1.031	0.151	7.023	0.975
2011	0.434	0.048	3.921	0.457
2012	1.863	0.269	12.907	0.529
2013	0.248	0.017	3.652	0.310
2014	0.455	0.032	6.438	0.560
2015	0.650	0.048	8.775	0.745
2016	2.481	0.348	17.690	0.365
Constant	0.000	0.000	0.148	0.012

[1]OR: odds ratio; [2]95% CI: 95% confidence interval [3]SEIFA tertile: postcode level socio-economic status from 1 (lowest) to 3 (highest tertile) [4]Intersection density: count of intersections within 1km of the crash [5]Traffic volume: sum of AADT for all legs of the closest intersection to the crash

Table 27: Logistic regression model for child and adolescent pedestrians and cyclists involved in crashes occurring >300m to 2km from the closest school, WA, 2006-2016

Predictor variables	OR[1]	95% CI[2]		p-value
Road user				
Cyclist	1.000			
Pedestrian	1.476	1.044	2.088	0.028
Gender				
Female	1.000			
Male	0.967	0.684	1.367	0.849
Age				
Under 6 years old	1.396	0.801	2.433	0.239
6 to 12 years old	1.000			
13 to 17 years old	1.217	0.844	1.755	0.293
Total students enrolled at closest school	1.001	1.001	1.001	0.000
During school zone operating time	1.099	0.787	1.536	0.578
Proportion of population of Indigenous origin	1.031	0.996	1.068	0.087
Postcode population aged 17 years of younger	1.000	1.000	1.000	0.004
Postcode level mean age	1.126	1.063	1.192	0.000
SEIFA[3] tertile 1	1.000			
SEIFA tertile 2	0.665	0.431	1.025	0.064
SEIFA tertile 3	0.667	0.417	1.067	0.091
Remoteness area				
Major city	1.000			
Inner regional	2.211	1.268	3.856	0.005
Outer regional	2.469	1.386	4.398	0.002
Remote	13.868	5.114	37.603	0.000
Very remote	8.419	1.819	38.964	0.006
Intersection density[4]	1.000	0.996	1.004	0.997
Traffic volume[5]	1.000	1.000	1.000	0.971
Crash year				
2006	1.000			
2007	0.911	0.437	1.901	0.804
2008	0.729	0.391	1.360	0.320
2009	0.556	0.286	1.079	0.083
2010	0.378	0.193	0.743	0.005
2011	0.606	0.327	1.122	0.111
2012	0.407	0.206	0.806	0.010
2013	0.526	0.264	1.047	0.067
2014	0.539	0.252	1.154	0.111
2015	0.188	0.067	0.526	0.001
2016	0.211	0.087	0.513	0.001
Constant	0.001	0.000	0.010	0.000

[1]OR: odds ratio; [2]95% CI: 95% confidence interval [3]SEIFA tertile: postcode level socio-economic status from 1 (lowest) to 3 (highest tertile) [4]Intersection density: count of intersections within 1km of the crash [5]Traffic volume: sum of AADT for all legs of the closest intersection to the crash