An In-Depth Investigation into Paediatric Motorcycle and Off-Road Vehicle Crashes

Christopher S Mulligan, Marijke Oomens, Bianca Albanese, Susan Adams, Julie Brown

Abstract We are conducting a prospective in-depth review of children aged 16 years and under who are admitted to any one of the three paediatric hospitals in the state of New South Wales, Australia, due to injuries caused by a crash on a powered off-road vehicle or motorcycle. We aim to characterise crash circumstances, injury patterns and severity in order to identify priority targets for the development of injury prevention countermeasures. In this ongoing study, we have analysed 25 crashes, involving 22 males and 3 females between the ages of 4 and 16 years of age. Most riders were injured on purpose built off-road motorcycles or quad bikes in the course of recreational riding or farm duties. Most crashes (n=19) occurred as a result of loss of control of the vehicle. A range of injuries to all body regions were observed. Injury severity varied, including 13 with minor injuries (Injury Severity Score (ISS) between 1-9), 6 with moderate injuries (ISS 10-15), 2 with severe injuries (ISS 16-24) and 4 with critical injuries (ISS 25 or greater).

Keywords motorcycle, off-road vehicle, paediatric, quad bike

I. INTRODUCTION

Injury from trauma is the leading cause of death and injury among Australian children [1]. Injuries from the use of powered two, three and four-wheeled vehicles are an important cause of injury in children. In Australia, and other developed countries, the majority of these incidents occur off-road [2-5]. The incidence is increasing; in the state of Victoria, it has been estimated that population-based rates of injuries from motorcycles are increasing at 9.6% per annum [6].

Powered two and three wheeled vehicles used by children come in many shapes and sizes. Different classes of vehicles were described by the American Academy of Paediatrics as follows – two-wheeled vehicles include mini-bikes, mini-cycles, trailbikes or trail-cycles, mopeds (bicycles with small unenclosed motors) and motorcycles designed for on-road use. Three-wheeled vehicles designed for off-road use are generally classified as an all-terrain vehicle (ATV) and in the literature are often grouped together with four wheeled ATVs or quad bikes [7].

Children use these vehicles for a number of reasons, including recreation, organised sport (e.g. motocross) and assisting with farm activities on rural properties [2-4]. In Australia, most resultant injuries are sustained off-road, however in developing countries where the motorcycle is the predominant mode of transport, the injury patterns differ - motorcycles are more often used on-road as the family vehicle and children are commonly transported as pillion passengers by adult riders [6][8][9].

A greater understanding of crash causation and the injury patterns in paediatric riders would help inform injury prevention strategies. However, most of the literature relating to off-road vehicle and motorcycle use in paediatric populations are medical/coronial record reviews, observational studies or surveys rather than prospective critical in-depth examinations of the incidents which allow for analysis of the specific risk factors in these riders. The data examined in retrospective record reviews can contain good detail about the demographics and general circumstances of incidents resulting in hospital admissions and death following off-road vehicle incidents, but is restricted to the data routinely collected for that record. This often only contains ad hoc details of the actual injury event. These reports do not contain the level of detail critical to understanding risk factors for injury, or detailed information required to prioritise the development of

Dr C Mulligan is a Masters of Surgery candidate at Neuroscience Research Australia through the University of New South Wales (email: c.mulligan@neura.edu.au, telephone: +612-9399-1632) in Sydney, Australia. M Oomens is a research Nurse at Neuroscience Research Australia, Randwick, Australia. B Albanese is a Research Assistant at Neuroscience Research Australia, Randwick, Australia. Dr J Brown is a Senior Research Fellow at Neuroscience Research Australia, Randwick, Australia. Dr S Adams is a Paediatric Surgeon at Sydney Children's Hospital, Randwick, Australia.

countermeasures to prevent these incidents and subsequent injury. This level of detail is particularly absent in the case of paediatric off-road motorcycling.

We are therefore undertaking a study of motorcycle and off-road vehicle crashes in children and adolescents aged 16 years and below, which will include in-depth examination of the crash scene, the vehicle and protective equipment used as well as interviews with the rider and/or their parent/guardian to reveal the circumstances surrounding the crash. This paper presents the first 25 cases from this study.

II. METHODS

The key objective of this study is to collect relevant demographic data, crash and injury information among Australian children admitted to three paediatric hospitals after using motorcycles or off-road vehicles.

Design

This study has similar conceptual design to previous adult on-road motorcycle crash studies [10]. The population base is motorcyclists and riders of off-road vehicles who are 16 years or under in the state of New South Wales (NSW), Australia. Motorcycles and off-road vehicles are defined as per the American Academy of Paediatrics and include two, three and four wheeled vehicles, used in any location, other than public roads (i.e. off-road) [7].

This study employs in-depth crash investigation techniques, which involves interviewing patients and families of children admitted to hospital following an off-road vehicle incident, and inspection of the incident site and inspection of the equipment used, including the vehicle and any protective equipment used.

Participants and recruitment

Eligible cases are riders of motorcycles or off-road vehicles who are injured in a crash and admitted to any of the three paediatric trauma hospitals in the state of NSW, Australia (population 7.5 million). The participating hospitals include Sydney Children's Hospital (Randwick, NSW), Westmead Hospitals (Westmead, NSW) and John Hunter Children's Hospital (Newcastle, NSW). Each of these hospitals admits patients 16 years old and under. Cases have been identified from the hospital data systems and trauma teams, which monitor admissions or inter-hospital transfers of injured children. Children meeting the inclusion criteria, and their families, were invited to participate by the investigators and trauma nurses either whilst they were an inpatient, or as soon after discharge as possible, if admitted and discharged out of business hours. Interviews were carried out either in hospital or soon after discharge, usually at the child's place of residence.

Data collection:

Case Interviews

After obtaining consent, the rider and/or their parent/carer were interviewed using a structured interview pro-forma. Information obtained included:

- Demographics and anthropomorphic data (age, sex, height and weight)
- Details of the crash event and awareness of the impending impact
- Estimates of speed based on speedometer (not usually applicable) or rider and bystander estimates
- Contributing factors and preceding circumstances including possible distractions
- Crash location, time of day, weather conditions
- The motorcycle or vehicle ridden
- Use and type of safety equipment (including clothing)
- Description of their injuries

Medical data

Hospital medical records of the rider were accessed, and data obtained pertaining to the admission record, trauma and intensive care unit (ICU) notes, integrated patient notes, operation reports, medical imaging and specialist consults were reviewed to extract injury details. Detailed injury descriptions were recorded and injuries were coded according to the Abbreviated Injury Scale (AIS), 2008 revision, with a Maximum Abbreviated

Injury Score (MAIS) assigned to each case [11]. The Injury Severity Score (ISS) was also calculated by summing the squares of the AIS score of the three highest ranked injuries in three separate ISS body regions[12].

Vehicle, equipment and scene inspection

Damage due to crash events was identified during inspections of the helmet and protective clothing that the rider was wearing at the time of the crash. This information was collected to allow an assessment of the injury protection performance of these items. All equipment was analysed for manufacturing type, damage sustained in the crash and conformity to the Australian Standard [13-14]. Vehicles were inspected by engineers, to confirm the details of the vehicle provided by the participant and to examine for impact locations and structural damage as a result of the crash, and and the most likely sources for the riders' injuries.

Accessible crash scenes were visited and photography, measurements and data on environmental and road-related features were collected and used to gain a greater understanding of the road and roadside factors involved in the crash. Inspections were carried out as soon as logistically possible after the crash event, usually within a month. All site inspections were carried out with the child and their parent/carer present to identify environmental factors, accident traces, final vehicle and rider positions and other information.

Consultation and Approvals

The study has been reviewed and approved by the Sydney Children's Hospitals Network Human Research Ethics Committee (HC23043). Written consent to participate was obtained.

III. RESULTS

The preliminary dataset contains 25 crashes involving children aged 4-16 years of age (median 11 years). A summary of these cases is presented in Table I, grouped in three age categories 4-8, 9-12, and 13-16 to ensure anonymity.

There were 22 males and three females. The ISS scores ranged from 1-35, with a mean of 11. There were 13 children with minor injury (ISS 1-9), six children with moderate injury (ISS 10-15), two with severe injury (ISS 16-24) and four with critical injury (ISS 25 or higher).

There were 22 crashes on powered two-wheel vehicles and three on four-wheeled vehicles. Most crashes on two-wheeled vehicles (n=19) were on purpose built off-road motorcycles (motocross, trail-bike or enduro motorbikes). All crashes occurred on private or commercial properties in rural or outer metropolitan areas. There was one case of a pillion passenger injury, all of the other crashes occurred where the injured child was the sole operator of the vehicle.

Seven of the crashes occurred in commercial motocross tracks or during organised competition or practice race days, in which there is responsible adult supervision and where the use of helmets and full protective gear that conforms to the relevant Australian Standards is mandatory and enforced (including boots, armour, googles, and gloves).

Weather conditions were fine or lightly cloudy for all crashes but three cases were on tracks where previous rain had caused the track to be wet or form puddles which were thought to be partly contributory to the crash event.

The most common cause of crashes, in the estimation of the rider, family or witnesses, was a loss of control of vehicle (n=19). A combination of environmental, vehicle and rider factors played a role in these events. This includes environmental factors such as wet surfaces, obstacles on or near the track such as fences or trees and poor quality track surfaces, with loose ground, divots or ruts in the track. Vehicle malfunction occurred in some cases including clutch and braking problems. Individual rider factors were also contributory such as a lack of riding skill and experience, as well as executive riding decisions (i.e. excessive speed). For example, seven crashes involved the rider attempting a jump. Other crashes involved riders being hit or colliding with another rider (n=4), being ejected from the vehicle as a pillion passenger (n=1) and a collision with an obstacle which was visually obscured (n=1).

Injuries

Table I gives a full description of the injuries sustained by each child and a summary of the primary injury source. There were five injuries affecting the head/neck (MAIS range 1-5), four the thorax (MAIS range 1-5), six

the abdomen/pelvis (MAIS range 1-3), four the upper limb (MAIS range 1-2) and six the lower limb (MAIS range 1-4). Soft tissue injuries and fractures were the most commonly observed injury types.

The median ISS of the crashes caused by a loss of control was 8 (mean 10, range 1-35) whilst the median for the other cases (for example, collisions with other riders or objects) was 5 (mean 12, range 1-30).

The most common sources of injury were the child striking the ground and contact with the child's own vehicle. Two children were also injured when they came into contact with fences. Of the five head/neck injuries, four occurred to riders wearing helmets. Of the head injuries, four involved head strikes with the ground. The primary sources of injury to the thorax and abdomen were contact with the handle bars, or the bike landing on top of the rider. The bike landing on the rider was also the source of a number of the extremity fractures (n=4). Alternatively, extremity fractures occurred following a fall from the bike and impact with the ground (n=8)

TABLE I
SUMMARY TABLE OF PAEDIATRIC MOTORCYCLE AND OFF-ROAD VEHICLE CRASHES

Age Range	Sex	Brief Crash Description	Cause of Injury	ISS	MAIS	Injuries
9-12	M	Motocross bike rider on bushwalking track, travelling at 20 km/hr. Hit tree root on track, causing the bike to kick up and its handlebars impacted rider's abdomen and loss of control of bike. Rider separated from bike diagonally over the right hand side of the bike.	Impact with bike handlebars	10	3	• Splenic laceration (grade 3) • Kidney contusion • Liver laceration with subcapsular haematoma • Abrasions left hip
4-8	M	Motocross bike riding with another child around a circular track on a private property. Both riders were travelling at 50 km/hr. Both riders were travelling in opposite directions and collided head-on at a blind crest in the track. Rider A swerved and was hit on the left-hand side by rider B, falling right, being pinned under his vehicle.	Direct collision with other rider	2	1	• Nasal bone fracture • Facial contusions • Lip laceration • Scrotal contusion and abrasions
9-12	M	Motocross bike riding with another child around a circular track on a private property. Both riders were travelling at 50 km/hr. Both riders were travelling in opposite directions and collided head-on at a blind crest in the track. Rider B hit rider A head-on, falling off his bike to his right-hand side onto an outstretched arm.	Direct collision with other rider and impact with ground	5	2	• Fracture distal radius and ulna, right. • Abrasions right lower leg
9-12	M	Motocross riding in private property at 50-80km/hr with adult rider following behind. Attempted a jump over a small gully, mistiming distance and impacting bike and ground. Adult rider witnessed rider impacting handlebars with wrist and then head. The seat impacted the rider's body. Rider then separated with bike and fell to ground.	Impact with bike and ground	24	3	• Liver laceration, grade 4 • Kidney laceration (right) • Pneumothorax (right) • Pulmonary contusions (right) • Fracture distal radius (left) • Forehead laceration • Amnesia, mild head injury
13-16	M	Quad bike riding while working on a private property to irrigate land. No protective gear or helmet. Unwitnessed fall from quad on steep embankment. Quad allegedly did not rollover. Rider cannot recall fall mechanism but was able to drive home, with 10-minute lucid interval before becoming confused, dizzy, vomiting and losing consciousness.	Fall from bike, impacting ground	35	5	• Extradural heamatoma - (left) with 8mm midline shift, infratentorial extension, causing tonsilar and tentorial herniation. • Parietal skull fracture extending into mastoid air cells • Subgaleal haematoma • Bilateral pneumothoraces • Bilateral lung contusions • Abrasions face, elbow, knee, hip, anterior chest

						wall
9-12	M	Motocross riding at 40-60km/hr, wearing a helmet and all gear. Lost control of bike on flat ground, falling onto grass.	Impact with ground	5	2	• Eyelid laceration (left) • Closed head injury (mild) with brief loss of consciousness
13-16	M	On a motorcycle training course with licensed instructor teaching safety and race techniques, with approximately 20 others. Practicing sequential small jumps on muddy track, hitting the first jump on an angle, causing him to land heavily on the face of the second jump, separating from bike. The bike remained on the second jump whilst he landed on the face of the third jump.	Impact with ground	17	4	• Subdural hemorrhage, supra-tentorial, 8mm depth • Retrograde and anterograde amnesia • Abrasions left shoulder, chin, hip, back
9-12	M	Motorcycle riding to a friend's house across through rural properties down a normally open track. A new barbed wire fence was recently put up across the track with 2-4 strands and no warning tags, colours or bags tied to it. The rider was travelling at 30km/hour and did not see the wires, hitting them at neck level, garroting him and causing separation from the bike and falling to the ground.	Direct collision with obscured obstacle (wire fence)	30	5	• Extensive open anterior neck and laryngeal injury: tracheal tear between cricoid and 1st tracheal ring. Avulsed and paralysed left vocal cord with loss of posterior half of cord, prolapsed right arytenoid. • Bilateral pneumothoraces • Pneumomediastinum • Lacerations bilateral lower limbs • Closed head injury (minor)
13-16	M	Motocross riding at an organised competition day. Was competing in his last race of the day, attempting a jump, which he took at speed, causing him to lose control upon landing and roll several times before coming to stop.	Impact with ground	10	2	• Fracture of T3 vertebra superior endplate with 15% loss of height • Interspinous ligament injury lumbar spine • Fracture head of radius (left) • Closed head injury with amnesia
13-16	M	Motocross riding at an organised track day event. He was travelling at approximately 80 km/hr on rough track. Rear tyre hit square edge before a jump, causing rear wheel to kick out to the left. As rider crested the jump, he separated from bike and it landed on him whilst he was rolling down the other side of the jump.	Impact with bike	33	5	• Tension pneumothorax right • Haemothorax right • Bilateral pulmonary contusions • Fracture C7 spinous process • Fracture T1,T2 spinous processes • Scapula fracture right
4-8	M	Riding as a pillion passenger on parent's lap on a quad bike. A faulty steering mechanism turned the bike abruptly, causing both passengers to separate from the bike forwards over the handlebars. Both landed on the ground prone.	Impact from ground	10	2	• Splenic laceration • Left lower arm and forearm abrasions
9-12	M	Dirt bike riding on flat area of private property with thick tufts of wet grass, travelling at approximately 40km/hr. Hit a tuft of grass causing the bike to fishtail, causing loss of control and bike rollover 3 times.	Impact from ground	3	1	• Contusions adrenal gland • Abrasions left forearm • Contusions right face • Amnesia
4-8	M	Motocross bike riding on commercial track. Attempting dirt jump approximately 60 cm high at peak. Approach jump at speed and lost control as he took the jump and landed on the ground, separating in mid-air. Bike bounced on dirt and landed directly on rider's leg.	Impact from bike	10	3	• Comminuted closed fractures mid-shaft tibia and fibula (left) • Lacerations lower limb (left) distal to fracture
13-16	M	Racing trail bikes with friends at a motocross park.	Impact from	4	2	• Laceration left knee

		Turning sharply left on gravel and bike slipped out to the right. Came off bike sideways. Rider landed on left side, stating laceration to his leg was from the bike's clutch lever.	bike and ground			• Soft tissue injury right wrist
13-16	M	Trail bike riding with friends on private property, attempting jumps over a dried river bed, with several previous successful attempts. The jump approach had deep ruts from previous jumps and on the 4th jump, rider got caught in a rut and slowed on the jump, causing him to land short, on front wheel only, causing loss of control and falling to ground, still on bike.	Impact from ground	10	3	• Fracture right femur – spiral fracture of distal diaphysis. • Right knee abrasion
9-12	M	Motocross riding with full gear and helmet on racing practice laps. Went over a hill, falling off due to loss of control, onto LHS, however uninjured from fall. Without the time to move off the track, another rider came over the hill behind him and his bike ran over the victim's leg.	Ran over by other rider	25	4	• Fracture right femur • Transection superficial femoral artery, right
13-16	F	Quad bike riding behind another quad bike rider. As the rider in front slowed and stopped on a curved area of track, she slowed down to stop. At the apex of the curve of the circuit she pulled on the front brake, it locked, and made the inside wheel bite into the inside circle and when practically stopped, the quad rolled outwards, up-side down.	Impact with ground	5	2	• Fracture distal radius and ulna (left) • Abrasions right leg
4-8	F	Trying mini-bike for the first time after receiving it as birthday present. Riding on grass outside the front of her home. Full protective gear. After only 5 minutes of riding, she hit a small bump and pulled back on the throttle – causing her to accelerate through a colourbond steel fence into neighbor's yard.	Impact with fence	1	1	• Thoracic spine soft tissue injury • Cervical spine soft tissue injury • Contusion right anterior thigh
9-12	F	Mini-bike riding a new bike, practicing gear changes for the first time in a car-park at ~15 km/hr. Child looked down to the right, looking for gear leavers (which are on the left), losing balance, falling to the right, with bike flipped over, landing directly on her.	Impact from bike	5	2	• Liver laceration, grade 2 • Contusions right forearm, right thigh
13-16	M	Riding dirt-bike slowly (10km/hr) on a private dirt road. Rider was in 1st gear and throttle got stuck. Could not engage gear whilst going uphill and used front brake, causing bike to fall over sideways. Rider was separated from bike when it fell on him, the foot peg striking his knee.	Impact from bike	1	1	• Laceration right knee large
13-16	M	Riding behind other rider in paddock. Front tyre went into ditch, locked up front wheel and rider ejected over handlebars forward. Somersaulted and rolled on ground.	Impact from ground	4	2	• Fracture left mid-shaft humerus
13-18	M	Riding in backyard paddock 60kph on new bike. Attempting small jump over path going uphill. Dug wheels in too deeply, landing short of anticipated landing area by 1-2m, falling onto right hand side.	Impact from ground	2	1	• Contusions left shoulder, left elbow, left lateral chest • Amnesia, retrograde
4-8	M	Riding new mini-bike around athletics field oval track on second day riding ever. Built up speed before negotiating corner, thereby unable to turn, so separated from bike before hitting perimeter fence.	Impact from fence	4	2	• Abrasion glans penis with urethral bleeding
9-12	M	Riding around enduro track on recreational ride with adult rider. Hit a puddle on road and tried to engage clutch, which did not work, causing him to accelerate into a berm, hitting it at speed causing him to become airborne, hitting a tree and injuring himself on ground contact.	Impact from tree and ground	10	3	• Femur fracture mid-shaft transverse (left) • Fracture olecranon, intra-articular • Contusion left shoulder
9-12	M	Rider on practice motocross day in front of adult rider, going slowly (5-10km/hr) around hairpin bend. Front wheel stuck in a rut, causing rider to fall off the side of the bike on corner. Rider A fell into path of other rider's bike, who took evasive manoeuvres, but did not have time to avoid his bike's exhaust pipe	Collision with other rider	1	1	• Deep dermal burn right scapula (1% total body surface area) • Abrasion right thigh

hitting the rider on the track.

IV. DISCUSSION

Establishing the causative factors responsible for paediatric motorcycle and off-road vehicle crashes and clear patterns of injury, are vital to identify and prioritise potential injury countermeasures.

One important observation in this series is the number of riders (n=13) who sustained injuries due to impact with the ground. These injuries include blunt force injuries such as intracranial bleeds, but also soft tissue and skin abrasions, lacerations and contusions. They occur in the context of high levels of helmet and protective gear use, highlighting the need for further investigation of the performance of impact protection in helmets and body armour. In the case of head injuries, in particular, this series highlights the need for further investigation into the performance and fit of child sized helmets in young riders.

Furthermore, the fact that several injuries occurred from impact with the bike itself, notably from handlebars or foot pegs, suggests that design modifications such as making these elements more frangible at the time of impact may be a potential way to mitigate injury.

We observed a large age range of injured children from the period of early childhood to adolescence (6-16 years as primary vehicle operator). Regulatory measures such as licensing age restrictions, mandatory training, or restrictions on the size or types of vehicles that children of certain ages can use have been raised as potential injury prevention measures [4][15]. Suggestions of a minimum age limit in the literature range from around 8 years [3] to 16-18 years [4][16].

However, focusing on age alone may be too simplistic. Childhood development (encompassing physical, cognitive and perceptual domains), progresses at different rates between individuals, so children of the same chronological age may have attained markedly different developmental milestones and abilities pertaining to the task of off-road riding. In addition, the physical demands of riding necessitate being large enough to reach and operate the steering, acceleration, clutch and brakes, which will vary with different sized children and different sized vehicles. With this in mind, some have proposed regulatory limits based on objective physical development milestones, rather than age alone. These include minimum rider height and body to vehicle weight ratios [2] [3]. Indeed, such regulations have been adopted by some motorcycle sporting associations. However, there are no indications in the literature regarding what the correct ratios may be or what effective training and/or competency levels might be required to minimize injury risk.

While this study does not provide a quantitative, population-level indication of the incidence of paediatric crashes at various ages, it does identify that the majority of crashes occur as a result of loss of control of the vehicle (most notably in failed attempts to perform jumps or tricks). A focus on children's physical, cognitive, perceptual and developmental stage and level of maturity is important for crash risk, but as yet, there are no validated tools to conduct a functional assessment of children riding which covers physical, sensory and cognitive domains. Such an instrument would allow for further in-depth examination into each of these domains and allow for more evidence-based training, rules and regulations.

This series broadly reflects the patterns of off-road vehicle and motorcycle use in the Australian context. The majority of use is outer metropolitan, regional or rural and the type of riding being performed is largely for recreational purposes, with a small number of injuries sustained in the course of farm work on family owned or operated properties. Furthermore, particularly in the recreational riding group, there were a significant proportion of riders who were injured in the course of organised competition or practice days, where the use of full protective gear and helmets is enforced. The injury prevention performance and damage to the helmet and gear is an ongoing avenue of investigation in this study, as their use and availability are important to injury prevention and mitigation [15-17].

The strengths of this ongoing study are that it prospectively examines a cohort of paediatric off-road vehicle and motorcycle crashes, providing a level of detail on crash causation and injury outcomes that are often not captured in studies examining a pre-existing dataset. Limitations are small numbers and reliance on recollection rather than contemporaneous recording of crash circumstances. For example, our data on the speeds are based on rider or witness estimates as the vehicles in questions are usually not fitted with speedometers. Furthermore, not all parents of eligible cases consented to participate, including two cases of crashes occasioning death.

It is important to note that around the world, children may use powered off-road vehicles and motorbikes primarily for other purposes, such as transportation, and be subject to different rules, regulations and cultural norms regarding riding behaviours, helmet and protective gear use. Thus, the patterns of injuries and causative factors for crashes may not be applicable in every circumstance.

This is an ongoing study for which we present some interesting preliminary observations as a case series. Further in-depth analysis of individual cases continues, as does investigation in to the performance of protective equipment.

V. CONCLUSIONS

Motorcycle and off-road vehicle crashes are an important cause of paediatric injury. This study presents a preliminary case series from an in-depth multi-disciplinary crash investigation study of children injured in these crashes. We have observed a wide range of injuries to all body regions with a range of injury severity, despite high levels of protective gear and helmet use. Primary injury sources for these children are contact with the ground, the vehicle being ridden and objects in the environment such as fences. This highlights the need for further investigation into the performance and potential of protective equipment to better attenuate energy, and closer examination of the potential for injury prevention through improved aspects of vehicle design. Further analysis of the developmental attributes of the child appropriate to the task of riding, as well as environmental factors, particularly in regard to the jumps will further inform our understanding of crash causation.

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