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Motorcycle protective clothing: Protection from injury or just the weather?

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ABSTRACT

Background: Apart from helmets, little is known about the effectiveness of motorcycle protective clothing in reducing injuries in crashes. The study aimed to quantify the association between usage of motorcycle clothing and injury in crashes.
Methods and findings: Cross-sectional analytic study. Crashed motorcyclists ($n = 212$, 71% of identified eligible cases) were recruited through hospitals and motorcycle repair services. Data was obtained through structured face-to-face interviews. The main outcome was hospitalization and motorcycle crash-related injury. Poisson regression was used to estimate relative risk (RR) and 95% confidence intervals for injury adjusting for potential confounders.
Results: Motorcyclists were significantly less likely to be admitted to hospital if they crashed wearing motorcycle jackets (RR = 0.79, 95% CI: 0.69–0.91), pants (RR = 0.49, 95% CI: 0.25–0.94), or gloves (RR = 0.41, 95% CI: 0.26–0.66). When garments included fitted body armour there was a significantly reduced risk of injury to the upper body (RR = 0.77, 95% CI: 0.66–0.89), hands and wrists (RR = 0.55, 95% CI: 0.38–0.81), legs (RR = 0.60, 95% CI: 0.40–0.90), feet and ankles (RR = 0.54, 95% CI: 0.35–0.83). Non-motorcycle boots were also associated with a reduced risk of injury compared to shoes or joggers (RR = 0.46, 95% CI: 0.28–0.75). No association between use of body armour and risk of fracture injuries was detected. A substantial proportion of motorcycle designed gloves (25.7%), jackets (29.7%) and pants (28.1%) were assessed to have failed due to material damage in the crash.
Conclusions: Motorcycle protective clothing is associated with reduced risk and severity of crash related injury and hospitalization, particularly when fitted with body armour. The proportion of clothing items that failed under crash conditions indicates a need for improved quality control. While mandating usage of protective clothing is not recommended, consideration could be given to providing incentives for usage of protective clothing, such as tax exemptions for safety gear, health insurance premium reductions and rebates.

1. Introduction

Motorcycles are the fastest growing sector of motor vehicles globally and comprise the majority of the fleet in many low and middle income countries. Their presence on the roads is mirrored in the increasing proportion of motorcycle crash casualties in both low and high income countries (WHO, 2004). Compared to car drivers, motorcyclists are more likely to be killed or severely injured in crashes (DFT, 2008; Lee et al., 2010). For many years motorcycle safety research has been dominated by debate about the effectiveness of helmets (Lawrence et al., 2002; Liu et al., 2008). There has been less focus on other protection for the riders body, although the protective value of materials such as leather have been known for at least 30 years (Feldkamp et al., 1977; Zettas et al., 1979; Aldman et al., 1981; Hurt et al., 1981a; Schuller et al., 1982, 1986; Otte and Middelhauve, 1987; Hell and Lob, 1993).

In Europe, standards have been developed for motorcycle protective clothing based on two mechanisms for protecting the motorcyclists body (EEVC, 1993). The first requires protection of soft tissues by material and construction that is abrasion, cut, tear and burst resistant (EU, 2002). The second requires the use of body armour or impact protectors (high-density foam shields) which absorb and distribute the force of direct impacts to exposed areas, e.g. elbows (EU, 1998). There are now separate standards

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for motorcycle protective gloves, boots, one piece suits, jackets and pants and body armour for the limbs and back. While only enforceable in Europe, the standards have provided benchmarks for manufacturers across the international market (de Rome, 2006). The result has been the emergence of a new generation of protective clothing products, however to date their performance in real world crashes has not been examined.

While there are limits to the extent clothing can prevent injury in high impact crashes, it is in low impact crashes that protective clothing is thought to offer the greatest injury reduction (Hell and Lob, 1993). The majority of motorcycle crashes do not involve high speeds nor impacts with fixed objects (EEVC, 1993; Noordzij et al., 2001; ACEM, 2004). However it is apparent that many riders who wear helmets do not fully protect the rest of their bodies (Hurt et al., 1981a; Reeder et al., 1996; ACEM, 2004; de Rome and Stanford, 2006; Wishart et al., 2009). Given the increasing human and economic costs of motorcycle injuries around the world, there is a clear need for research to establish the effectiveness of motorcycle protective clothing.

2. Methods

The aim of the study was to examine the association between use of motorcycle protective clothing and risk of injury in crashes.

A 12 month prospective cohort study of motorcycle crashes was conducted from June 2008. Eligible participants were residents of the study area, aged 17–70 years, who were riders or passengers involved in motorcycle crashes causing injury or vehicle damage, on public roads within the Australian Capital Territory (ACT). Motorcyclists were excluded if they scored <13 on the Glasgow Coma Scale (GCS), sustained severe head (3+) or spinal injuries (4+) on the Abbreviated Injury Scale (AIS), or were otherwise unable to provide informed consent (Teasdale and Jennett, 1974; AAAM, 2005).

The ACT consists of an urban centre with a population of 354,900 (ABS, 2010) surrounded by a rural region. Potential participants were identified through the two hospitals and/or thirteen motorcycle crash repairers servicing the area. Repair services received a recruitment fee to obtain written consent and contact details from customers who had been involved in road crashes. Potential participants were mailed information and telephoned to invite their participation in the study.

Participants were interviewed face–face approximately two weeks after their crash and surveyed by mail after six weeks and six months. The interview format was based on the OECD methodology for motorcycle crash investigation (OECD, 2001). Information about the crash, the type and speed of impact, clothing worn and injury details were collected, in addition to demographic details and information relating to their riding experience and exposure. External clothing worn and any evidence of crash impact was photographed. Participants also completed six questionnaires about their general health prior to the crash. These were repeated in the follow up surveys on the longer term consequences of the crash, the findings of which are not reported here.

Injury details were recorded by location: hands/wrists, upper body (including arms, shoulders, chest, abdomen and upper back), lower body (including hips, lower back and legs) and feet/ankles. Injuries were classified by type: soft tissue (abrasion, cuts, laceration, bruises and burns), joint damage (sprains and dislocations), fractures and internal injuries. Injury details, including location and dimensions, were recorded on a body outline diagram by the interviewer and subsequently independently scored on the AIS scale by a trained assessor. The medical records of participants who attended hospital were used to corroborate interview reports on injuries and admissions details.

The current article is a cross-sectional analysis of the baseline data. The main outcomes reported are injury by body zone and admission to hospital. Self-reported injury data obtained at interview was used for this analysis, as it was available for all participants and provided more detail on minor injuries than available in emergency department records. The main exposure was use of motorcycle protective clothing with or without body armour. Motorcycle clothing not designed for injury protection (e.g. weather protection) was not included.

Sample size estimates were based on the expected exposure (protection) and outcome (injury) rates for each body zones. The expected protection rates for each body zone was based on a recent Australian survey of riders (de Rome and Brandon, 2007). The expected injury rates in unprotected riders were based on those reported by Hurt et al. (1981b). The largest sample was required for the upper body based on an expected 12% unprotected (de Rome and Brandon, 2007) and 58% of unprotected being injured (Hurt et al., 1981b). A sample of 201 was required to detect a 30% difference in the proportion of protected and unprotected riders with injuries to their upper body, based on a test for two independent proportions with a target level of $\alpha = 0.05$ and power of 80%.

Age was categorised into identified motorcycle crash risk age groups (ATSB, 2002). The impacts causing injury to the motorcyclists' body were classified into 5 types and up to 4 separate impacts were recorded per motorcyclist.

Ethical approval for the study was obtained from the Human Research Ethics Committees (HREC) for ACT Health and Calvary Health Care. The study was endorsed by the main local motorcycle community organisations.

Relative risk ratios were selected as the appropriate means of comparison as this was a cross-sectional study and the outcomes of interest were relatively common (incidence greater than 10%) (Zou, 2004). To avoid convergence issues encountered with the log-binomial model, the Poisson model with sandwich variance estimator was used to compute adjusted relative risks (Spiegelman and Hertsmark, 2005; Lumley et al., 2006). The analysis computed the relative risk for injury to each part of the body by level of protection. Poisson regression models were used to estimate the relative risk (RR) and corresponding 95% confidence intervals for hospitalization and, separately, for injury to each body zone by injury type. Tests of association were adjusted for potential confounders of injury identified from the literature including the age and gender of the motorcyclist; type of motorcycle; type of crash (single or multi-vehicle); type of impact (e.g. road surface, other vehicle or fixed object); and the estimated speed of impact (Lin et al., 2003; Zambon and Hasselberg, 2006; Pai and Saleh, 2007).

As it was likely that riders who were not injured were underrepresented in the study, a sensitivity analysis was conducted. The analysis was re-run on the subset of participants who were recruited from hospital, excluding those recruited via other means.

Analysis was conducted in SAS 9.1 (SAS, 2008).

3. Results

Over the study period the researchers identified 618 crashed motorcyclists, including 298 who had been involved in a road crash within the ACT and met all eligible criteria for inclusion in the study. Of these 298 eligible motorcyclists 71.1% ($n = 212$) participated, 20% ($n = 59$) could not be contacted, 8% ($n = 24$) declined and 1% ($n = 3$) were excluded on medical grounds. The 212 participants included 126 (59.4%) identified from hospital presentations, 75 (35.4%) from crash repair services and 9 self-referred (4.2%). There were no significant differences in age or sex between eligible participating and non-participating riders identified through hospitals.

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Table 1
Key features of participants, clothing worn and the crash event.

Factor *n* (%)							
Gender	Male	Female					
	184 (86.8)	28 (13.2)					
Age group	17–25	26–39	40–75				
	61 (29.3)	90 (42.5)	60 (28.3)				
Motorcycle licence	None	Learner	Provisional	Full			
	5 (2.4)	54 (25.5)	25 (11.8)	128 (60.4)			
Type of motorcycle	Standard/Scooter	Touring/Cruiser	Supersport/Sport/	Off-road			
	36 (17.0)	60 (28.3)	106 (50.0)	10 (4.7)			
Hospitalization	No medical treatment	Medical treatment only	Admitted to hospital				
	39 (18.4)	124 (58.5)	49 (23.1)				
MAIS (Most serious injury)	0	1	2	3	4	5	6
	3 (1.4)	156 (73.6)	36 (17.0)	12 (5.7)	3 (1.4)	1 (0.5)	1 (0.5)
Motorcycle clothing	Helmet	Jacket	Pants	Gloves	Boots		
Worn (n)	209 (98.6)	175 (82.6)	74 (34.9)	185 (87.3)	81 (38.2)		
Impact sustained	126 (60.3)	142 (81.1)	55 (74.3)	120 (64.9)	54 (66.7)		
Garment damaged	139 (66.5)	115 (65.7)	42 (56.8)	101 (54.6)	56 (69.1)		
Clothing failure							
Material[a]	NA	52 (29.7)	52 (28.1)	19 (25.7)	7 (8.6)		
Seams/fastenings	NA	18 (10.3)	2 (2.7)	14 (7.6)	5 (6.2)		
Impact protection	Upper limb	Lower limb	Hand/wrist	Foot/ankle	Back/spine		
Worn (n)	153 (72.2)	21 (9.9)	109 (51.4)	66 (31.1)	40 (18.9)		
Impact sustained	103 (67.3)	10 (47.6)	120 (64.9)	54 (66.7)	22 (55.0)		
Crash type	Single vehicle	Multi vehicle	Animal on road				
	89 (42.0)	104 (49.1)	19 (9.0)				
Type of impact	Loss of control	Collision (object/vehicle)					
	100 (47.2)	112 (52.8)					
Impact speed[b]	0–20	21–40	41–60	61–120	Unknown		
	56 (26.4)	65 (30.7)	39 (18.4)	35 (16.5)	17 (8.0)		
Sustained direct impact to body	Yes	No					
	162 (76.4)	50 (23.6)					
Injuries due to[c]	Road surface	Slid on road	Own motorcycle	Other vehicle	Fixed object		
	178 (84.0)	139 (65.6)	70 (33.0)	350 (16.5)	31 (14.6)		

[a] Material failure is defined by holes in the protective layer.
[b] Speed of impact is based on motorcyclist estimations.
[c] Percentages refer to the proportion of motorcyclists who sustained each type of impact and are not additive. Up to four different impacts causing injury were recorded for each motorcyclist.

The 320 motorcyclists classified as ineligible either lived ($n = 66$, 21%) or crashed outside the study area ($n = 63$, 20%), crashed off-road ($n = 159$, 50%), or were misclassified or double counted by crash repairer and hospital ($n = 32$, 9%).

Study participants included 49 (23.1%) admitted to hospital, 124 (58.8%) who required some medical treatment and 39 (18.4%) who did not seek medical treatment. The majority (73.6%, $n = 156$) sustained minor injuries (AIS 1) with only 1% ($n = 3$) uninjured (AAAM, 2005). Almost half of the crashes (49%) involved another vehicle, 42% were single vehicle and 9% involved an animal, usually a kangaroo on the road. Over the same period, 283 motorcycle road crashes were reported to ACT police, these included 100 injury crashes and 183 involving property damage only (ACT Roads, 2010).

Table 1 summarises key demographic and crash characteristics of the sample. Nearly all participants wore helmets (98.6%), motorcycle jackets (82.5%) and motorcycle gloves (87.3%). Fewer wore motorcycle pants (34.9%), motorcycle boots (38.2%) or other heavy boots (25.9%). Body armour was worn over shoulders and elbows (71.7%), hands (50.9%), feet/ankles (29.7%) backs (18.9%), knees 9.9% and hips (7.6%). Almost half (45.8%) wore foam inserts in their jacket backs.

A high proportion of the motorcycle clothing showed signs of crash impact. Over a quarter of the pants (28.1%), jackets (29.7%) and gloves (25.7%) were assessed as having failed because the protective layer was holed potentially exposing the wearer to injury. The most common form of damage was due to material erosion with little evidence of tear, cut, sharp penetration or crush damage.

Table 2 shows the proportions of motorcyclists by types of injury and type of protection worn. The most common injuries were cuts, abrasions and bruises followed by sprains mostly to the upper torso. Fractures were less common and more likely to affect upper limbs. Hospital records showed a close correspondence with injury reports obtained at interview for those participants who attended hospital with 88% agreement on the number with long bone (legs and arms) fractures. There was less agreement in relation to small bone fractures with hospital records accounting for only 57% ($n = 4/7$) of the foot and ankle fractures and 39% (11/28) of the hand and wrist fractures that were reported at interview.

Overall riders were significantly less likely to be admitted to hospital if they crashed while wearing a motorcycle jacket (RR = 0.79, 95% CI: 0.69–0.91), motorcycle pants (RR = 0.49, 95% CI: 0.25–0.94), or motorcycle gloves (RR = 0.41, 95% CI: 0.26–0.66). The effect of motorcycle boots on hospitalization was not significant (RR = 1.04, 95% CI: 0.59–1.83). These ratios are adjusted for age, gender, motorcycle type, single or multivehicle crash, impact type and the rider's estimate of impact speed.

Table 3 presents the unadjusted and adjusted relative risk (RR) for motorcyclist injuries associated with motorcycle clothing with and without body armour, compared to non-motorcycle clothing. The RR represents the benefit, if any, of the particular item of protective clothing in reducing the risk of each type of injury to the relevant part of the body.

Motorcyclists wearing motorcycle protective clothing fitted with body armour, were significantly less likely to sustain injuries to the protected areas compared to those wearing non-motorcycle clothing. Specifically, when body armour was fitted, there was a 23% lower risk of injury associated with motorcycle jackets (RR = 0.77, 95% CI: 0.68–0.86), 45% for motorcycle gloves (RR = 55, 95% CI: 0.37–0.81), 39% for motorcycle pants for leg injuries only (RR = 0.61, 95% CI: 0.41–0.91 and 45% by motorcycle boots (RR = 0.55, 95% CI:

Table 2
Proportion of different types of injuries by type of protection worn.

Motorcycle clothing worn	Total $n = 212$	Any injury (%)	Bruised (%)	Abrasions/cuts (%)	Fracture (%)	Sprain (%)	Internal (%)
Motorcycle jacket							
No	37	91.9%	43.2	56.8	21.6	29.7	0.0
Yes	23	78.3%	39.1	26.1	13.0	52.2	0.0
Yes with body armour	152	69.7%	31.6	25.7	9.9	35.5	0.7
Motorcycle gloves							
No	27	66.7%	25.9	55.6	7.4	18.5	0.0
Yes	77	49.4%	26.0	18.2	13.0	18.2	0.0
Yes with body armour	108	35.2%	12.0	14.8	8.3	11.1	0.0
Motorcycle pants							
No	138	92.0%	61.6	72.5	5.1	19.6	2.9
Yes	53	84.9%	64.2	49.1	1.9	18.9	1.9
Yes with body armour	21	71.4%	61.9	33.3	4.8	4.8	9.5
Motorcycle boots							
No (shoes/joggers)	76	55.3%	28.9	30.3	9.2	15.8	1.3
No (other boots)	57	26.3%	14.0	8.8	3.5	14.0	0.0
Yes	17	35.3%	23.5	5.9	5.9	17.6	0.0
Yes with body armour	62	32.3%	16.1	4.8	6.5	14.5	4.8
Helmet							
No	3	60.0%	0.0	33.3	33.3	33.3	66.7
Open face	26	19.2%	11.5	15.4	3.8	11.5	19.2
Full face	183	15.5%	9.3	2.7	0.0	8.7	15.8
Motorcycle back protector							
No	75	10.7%	5.3	2.7	1.3	6.7	0.0
Foam insert	97	21.6%	3.1	3.1	2.1	16.5	0.0
Back armour	40	7.5%	2.5	2.5	2.5	0.0	0.0

0.35–0.85). The risk of any foot or ankle injuries was reduced 53% by non-motorcycle boots (RR = 0.47, 95% CI: 0.28–0.77) when compared to shoes or joggers, a risk reduction similar to motorcycle boots.

The results for motorcycle jackets and gloves were confirmed in the sensitivity analysis when non-hospital recruits were excluded, however the analysis for motorcycle pants and boots failed to converge, most likely due to insufficient numbers.

There was an increased risk of back injury associated with usage of foam inserts in the backs of jackets (RR = 2.16, 95% CI: 1.08–4.36).

Table 4 presents the adjusted relative risk (RR) for types of injury according to the protection worn.

Table 3
Unadjusted and adjusted relative risk for any injuries sustained by level of protection.

Type of clothing	Injuries sustained (n) No	Injuries sustained (n) Yes	Unadjusted RR	95% Confidence interval	Adjusted RR[a]	95% Confidence interval
Upper body						
No motorcycle jacket	3	34	Reference		Reference	
Motorcycle jacket	5	18	0.85[NS]	0.67–1.08	0.83[NS]	0.65–1.05
Motorcycle jacket + BA[b]	46	106	0.76[e]	0.66–0.87	0.77[f]	0.68–0.86
Hand/wrist injuries						
No motorcycle gloves	9	18	Reference		Reference	
Motorcycle gloves	39	38	0.73[NS]	0.51–1.04	0.69[NS]	0.46–1.04
Motorcycle gloves + BA[b]	70	38	0.53[e]	0.36–0.76	0.55[d]	0.37–0.81
Lower body injuries						
No motorcycle pants	11	127	Reference		Reference	
Motorcycle pants	8	45	0.92[NS]	0.81–1.04	0.93[NS]	0.82–1.05
Motorcycle pants + BA[b]	6	15	0.77[NS]	0.59–1.01	0.79[NS]	0.61–1.02
Leg injuries only						
No motorcycle pants	21	117	Reference		Reference	
Motorcycle pants	13	40	0.88[NS]	0.75–1.05	0.89[NS]	0.75–1.06
Motorcycle pants + BA[b]	10	11	0.61[c]	0.41–0.93	0.61[d]	0.41–0.91
Feet/ankles						
Shoes/joggers	34	42	Reference		Reference	
Non-motorcycle boots	42	15	0.47[d]	0.29–0.76	0.47[d]	0.28–0.77
Motorcycle boots	11	6	0.63[NS]	0.32–1.24	0.56[NS]	0.27–1.17
Motorcycle boots + BA[b]	42	20	0.58[d]	0.38–0.87	0.55[d]	0.35–0.85
Back/Spine						
No back protection	67	8	Reference		Reference	
Foam insert in jacket	76	21	2.00[NS]	0.94–4.27	2.16[c]	1.08–4.36
Separate back armour	37	3	0.69[NS]	0.19–2.47	0.77[NS]	0.22–2.64

NS = non-significant.
[a] Adjusted for age, gender, motorcycle type, crash type (single or multivehicle), impact type (slid, object, other road user) and impact speed.
[b] BA – garment had body armour incorporated.
[c] $p \leq 0.05$.
[d] $p \leq 0.01$.
[e] $p \leq 0.001$.
[f] $p < 0.0001$

Table 4
Adjusted relative risk of soft tissue, open wound and fracture injuries by level of protection.

Injuries sustained	All soft tissue[c]		Open wounds[d]		Fractures	
Area/type of clothing	Adj. RR[a]	95% CI	Adj. RR[a]	95% CI	Adj. RR[a]	95% CI
Upper body[b]						
No motorcycle jacket	Reference		Reference		Reference	
Motorcycle jacket	0.73[NS]	0.49–1.07	0.42[f]	0.17–1.01	0.59[NS]	0.16–2.16
Motorcycle jacket + BA	0.67[h]	0.53–0.84	0.37[i]	0.25–0.55	0.48[NS]	0.22–1.06
Hand/wrist injuries						
No motorcycle glove	Reference		Reference		Reference	
Motorcycle gloves	0.60[f]	0.38–0.96	0.30[h]	0.15–0.59	1.42[NS]	0.29–7.08
Motorcycle gloves + BA	0.38[i]	0.24–0.60	0.27[i]	0.15–0.49	1.24[NS]	0.26–5.90
Lower body injuries[e]						
No motorcycle pants	Reference		Reference		Reference	
Motorcycle pants	0.92[NS]	0.78–1.08	0.62[g]	0.42–0.90	0.51[NS]	0.12–2.23
Motorcycle pants + BA	0.66[f]	0.44–0.97	0.41[f]	0.20–0.85	1.15[NS]	0.39–3.42
Leg injuries						
No motorcycle pants	Reference		Reference			
Motorcycle pants	0.87[NS]	0.68–1.09	0.63[f]	0.42–0.95	NA	
Motorcycle pants + BA	0.53[f]	0.31–0.90	0.09[g]	0.01–0.60		
Feet/ankles						
Shoes/joggers	Reference		Reference		Reference	
Non-motorcycle boots	0.39[g]	0.22–0.70	0.24[g]	0.10–0.58	0.27[NS]	0.06–1.32
Motorcycle boots	0.35[f]	0.13–0.91	0.17[NS]	0.02–1.47	0.48[NS]	0.07–3.58
Motorcycle boots + BA	0.31[i]	0.17–0.55	0.10[h]	0.03–0.34	0.43[NS]	0.12–1.51
Back/Spine						
No back protection	Reference					
Foam insert in jacket	0.99[NS]	0.28–3.50	NA		NA	
Separate back armour	0.96[NS]	0.20–4.65				

BA – Garment had impact protection incorporated.
NA – data not available due to small numbers and convergence issues.
[a] Adjusted for age, gender, motorcycle type, crash type (single or multivehicle), impact type and impact speed.
[b] Upper body fractures to arms, elbows or shoulders only.
[c] All soft tissue injuries include bruises, abrasions, cuts and lacerations.
[d] Open wounds include abrasions, cuts and lacerations but excludes bruises.
[e] Lower body fractures adjusted for age gender only due to convergence issues.
[f] $p \leq 0.05$.
[g] $p \leq 0.01$.
[h] $p \leq 0.001$.
[i] $p < .0001$

There was a significant reduction in the risk of any soft tissue injuries (including bruises, abrasions, cuts and lacerations) associated with all forms of motorcycle clothing fitted with body armour.

Where body armour was not fitted, motorcycle gloves (RR = 0.60, 95% CI: 0.38–0.96); and motorcycle boots (RR = 0.35, 95% CI: 0.13–0.91) still provided a reduced risk of soft tissue injuries as did non-motorcycle boots (RR = 0.39, 95% CI: 0.22–0.70), however no significant reduction was observed for motorcycle jackets or pants.

When bruises were excluded from the list of soft tissue injuries, there was a significant reduction in the risk of open wounds (abrasions, cuts and lacerations) associated with all forms of motorcycle clothing fitted with body armour, and for gloves and pants when body armour was not present (see Table 4). However there was no evidence of a reduction in the risk of fractures associated with body armour for any area of the body.

4. Discussion

These findings confirm earlier reports on the value of abrasion resistant materials in the reduction of soft tissue injuries in motorcycle crashes (Aldman et al., 1981; Hurt et al., 1981a; Schuller et al., 1982; Otte et al., 2002b). This study takes that work further and is the first detailed examination of the performance of motorcycle clothing in crashes since standards for protective clothing were established in Europe (CEC, 1989).

These results suggest considerable potential to reduce the human costs of non-fatal motorcycle crash injuries. In Australia motorcyclist account for 22% (n = 6270) of all seriously injured road casualties each year, with an estimated human costs for a hospitalized injury of approximately AUS$214 000 per injury (including disability-related costs) (AIHW, 2009; BITRE, 2009). By comparison in the US, the total lifetime costs for all non-fatally injured motorcyclists in 2005 are estimated to be US$3992 million for hospitalized injuries and US$1046 million for ED treated only (Naumann et al., 2010).

The reduced risk of hospitalization observed in this study suggests that motorcycle clothing can significantly reduce the severity of injures in crashes. While the greatest benefits observed were in relation to the prevention of soft tissue, and particularly open wound, injuries, this is not a trivial outcome. Such injuries are rarely life threatening, but can have serious consequences for the motorcyclist such as opportunistic infections, scarring, loss of mobility and longer term disability. A New Zealand study of disabled motorcyclists found a high proportion (80%) had impairments due to disfiguring and scarring from soft tissue injuries (Clarke and Langley, 1995).

The most important result relates to the contribution of body armour, which was associated with substantial reductions in the risk of any injury in crashes when other factors such as speed and type of impact were controlled. This is the first evidence of the effectiveness of body armour from crash studies, although it has previously shown promise in laboratory tests (Otte and Middelhauve, 1987; Otte et al., 2002a). The reduced risk of injuries to the legs in motorcycle crashes is particularly important because legs are most likely to be injured but least likely to be protected (Hurt et al., 1981b; Lateef, 2002; ACEM, 2004; Chen, 2006; de Rome, 2006; Watson et al., 2008).

While motorcycle boots were not associated with a significant reduction in risk of hospitalization, the results did confirm the benefits of motorcycle boots and, in fact, any type of sturdy boots compared to shoes such as joggers, It would appear that the basic elements of protection are not unique to motorcycle boots, but can be provided by other boots. Whether this is due to the additional coverage for the ankles, or because shoes are more likely to be torn off during a crash is unclear and requires further investigation.

Motorcycle gloves and pants not fitted with body armour were also associated with a reduced risk of open wound injuries. The absence of effect for motorcycle jackets ($n = 23$) and motorcycle boots ($n = 17$) was unexpected but may be due to a lack of power given the small numbers not fitted with body armour. It may also be due to a lack of quality in some products, noting the material erosion of 29% of jackets or to a lack of differentiation from non-motorcycle garments which did include some heavy jackets. While material erosion also occurred in jackets that were fitted with body armour, the armour is likely to have provided an additional shield from cuts and abrasions quite apart from its primary function of impact protection.

Small numbers may also explain the lack of effect for back armour. However, other research suggests that most motorcycle-crash back injuries are caused by bending and torsional forces, not direct impacts to the spine (EU, 2003). The back sprain injuries in those wearing foam inserts may be due to such bending and twisting forces, but it is hard to explain why that group should be more at risk than motorcyclist without any protection. This certainly warrants further investigation in laboratory-based studies and future in-depth research.

Despite the reduced risk of any injuries when wearing body armour, the benefits could not be detected specifically in relation to fractures. Given the relatively low occurrence of fractures (15%), compared to soft tissue injuries (71%), in unprotected motorcyclists (Duffy and Blair, 1991) the sample size was likely too small to be able to detect any such difference. Further research is necessary to explore the benefits of products such as body armour for different parts of the body in crashes in relation to specific injury types, particularly fractures.

The injury reduction effects observed here gives rise to the question of mandatory use of protective clothing in addition to helmets. However, mandating use of protective equipment is unlikely to be either feasible or effective, given known ergonomic issues, the lack of global standards and the lack of quality control in motorcycle protective clothing as evidenced by the failure rates in this study.

Conflict between primary safety (accident avoidance) and secondary safety (injury protection) is associated with protective clothing in many industries. This is because the materials required to provide injury protection tend to be heavy and may negatively affecting the operators' ability to perform safely (Nunneley and Myhre, 1976; Bittel et al., 1992; EEVC, 1993; Koch, 1996; James, 2002). Earlier reports on motorcycle protective clothing cautioned that such materials may increase riders' crash risk due to discomfort and heat fatigue, however to date there does not appear to have been any research into this (EEVC, 1993; Koch, 1996).

The challenge for industry has been to provide protection from injury and the weather without restricting the motorcyclists' ease of movement nor creating discomfort or fatigue. The European Standards for motorcycle protective clothing require that garments withstand the forces of a crash within set limits (EU, 2002). While the forces involved in some crashes will exceed these limits, the clothing failure rate found in this study suggests a need for improved quality control. Particularly as over half of the crashes (57.1%) involved estimated impact speeds less than 40 kmh with only 16.5% over 60 kmh. The failure rate is also consistent with reports from independent tests of motorcycle clothing conducted in the United Kingdom (Ride, 2009a,b). As the market for motorcycle clothing involves a diverse international industry, such consumer driven information systems may more viable and more effective than regulation in the short-to-medium term. They could also provide manufacturers with the incentives and market certainty to improve product quality and discourage the production of inferior products. Preliminary work has recommended using the European Standards as the benchmark for independent evaluations in Australia (de Rome, 2005; Haworth et al., 2007).

The strength of this study was the attempt to obtain a representative sample by the inclusion of both injury and non-injury motorcycle crashes. Previous studies have focused on injury and/or police reported crashes thus biasing their sample towards more severe crashes and potentially excluding those where protective clothing had proved effective. Helmet usage by participants was high a finding indicative of high levels of compliance with mandatory helmet laws in Australia. Other motorcycle protective clothing is not required by law, but usage rates in the study were consistent with those reported in an observational study of riders in the same region which included both commuter and recreational riding routes (Watson et al., 2008). The use of face to face interviews to obtain injury details allowed for comprehensive itemization of soft tissue injuries, which are less likely to be documented in Emergency Department records.

A limitation of the study was the reliance on self-report without independent investigation of the crash scenes or vehicles. Factors such as impact speed were therefore uncorroborated; however the distribution of the estimated impact speed reported by participants (Table 1) is consistent with that reported in studies where the crash speed was estimated objectively (ACEM, 2004). A further limitation is that the participation rate for crashes where the rider did not attend a hospital cannot be determined. The number of referrals provided by each of the nine crash repair services, which actively participated, was consistent with pre-study estimates of their turnover. The number of possible referrals not referred by the four non-participating companies is not known, although some of their customers were recruited through hospital presentations. While the number of injury crashes included in the study is greater than that recorded by police, the number of non-injury crashes is substantially less. The consequences of less serious crashes being under represented in the sample, means the size of the reported benefits may be underestimated. However, a sensitivity analysis which included only those who were admitted to hospital showed similar results to the main results, so any effect is likely to be minimal. In addition, there were no significant differences in the age or sex of eligible participating and non-participating riders identified through hospitals. Finally as a cross-sectional study, the design is not ideal to evaluate the effectiveness of interventions, so these results require confirmation by other studies.

5. Conclusions

This study demonstrates that motorcycle protective clothing is associated with a significantly reduced risk of injury in crashes, particularly when body armour is fitted. While the most substantial effect was observed for open wound injuries, crashed motorcyclists who were wearing motorcycle clothing were also significantly less likely to require admission to a hospital.

These findings have implications for policy decisions related to encouraging the use of motorcycle protective clothing, however mandating use is not recommended at this stage. The failure rate for jackets, pants and gloves indicates a need to establish systems to ensure such products are fit for the purpose. Consideration could be given to providing incentives for the use of 'recommended' gear, such as tax waivers for safety gear, health insurance premium reductions and rebates.

Future research would be well served to examine the association, if any, between body armour for different parts of the body and

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injury, particularly fractures, however the findings here suggest a large-scale study would be required. Finally, it is also recommended that the association between motorcyclists' crash risk and usage of protective clothing in hot weather be investigated.

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