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Introduction

Motorcycle crashes represent a significant health burden to the community, accounting for 22% of serious casualties on Australian roads each year. In addition, it is well known and accepted that motorcyclists are significantly overrepresented in crashes given that motorcycle usage accounts for only one percent of vehicle kilometres travelled (ATC, 2011; BITRE, 2009).

Soft tissue injuries are the most common injuries experienced by crashed motorcyclists (NSAI, 1998, 2003, 2010). Protective clothing has been developed to help prevent these injuries, yet the performance of protective clothing in Australia is still variable (de Rome et al., 2011). In Australia, while there are no design standards for motorcycle protective clothing, there are non-mandatory Australian Guidelines for manufacturing. However, the guidelines specify the use of an abrasion testing machine which is not designed for the purpose of testing motorcycle protective clothing. Therefore, at present in Australia, there are no mechanisms in place to help maintain a high quality of performance.

There is a European Standard for motorcycle protective clothing and this Standard specifies the general requirements for clothing intended to protect the rider against mechanical injury. This Standard (EN13595) was developed from work undertaken by Woods who examined crash damage to 100 motorcycle suits (99 leather and 1 Kevlar) and observed where damage most frequently occurred as well as the type of damage. Based on the damage distribution, a clothing template was developed that specified four zones, each with different levels of protection dependent upon the clothing's ability to resist the main types of damage: burst, cut, abrasion and tear. (Woods, 1996a, 1996b).

It is still unknown how well the performance of materials in the laboratory tests of EN13595 relates to the performance of clothing in real world motorcycle crashes. With a larger variety of fabrics currently available to motorcycle riders, the performance of clothing in the real world may have varied since Woods developed the Cambridge Abrasion machine in 1996. There is a need to validate the observations on which the EU Standard requirements are based, particularly using a greater range of materials and more modern materials. Additionally, there has been no study since the work of Woods (Woods, 1996b) that examines the adequacy of the test methods. The objective of this study was to address this gap and, as abrasion resistance is considered to be the highest priority compared to other damage types (Meredith, Brown, Ivers, & de Rome, 2013), this study set out to determine whether the approach taken to assess abrasion resistance in the EU Standard is appropriate. Specifically, the aim of this study was to examine the relationship between the abrasion resistance performance of the clothing worn by the motorcycle riders when tested as required in EN13595 and the probability of real world injury outcome.

Method

To address the study aims, the study examined the abrasion resistance of clothing obtained from crash-involved riders and then compared this to the riders' injury outcomes.

Sample.
Data was collected during in-depth crash investigation. Motorcycle riders who had been involved in motorcycle crashes were recruited from three Sydney hospitals and one regional hospital from August 2012 to August 2014. Riders had to be at least 16 years of age. Following recruitment, riders completed a face-to-face interview and hospital medical records were reviewed. The crash scene and motorcycle ridden were also inspected. Where possible, clothing was inspected and collected from riders for testing. Clothing was sometimes unable to be inspected or collected due to the clothing having been thrown out, sent to insurance companies or lack of rider consent. If the clothing was inspected and photographed but the rider did not consent for the clothing to be kept and tested, the brand name and model of the clothing was recorded and new clothing items were purchased to the same specification.

Test methodology.

The testing apparatus and methods were based on the test procedures outlined in EN13595. However, as the test equipment used at NeuRA is known to abrade materials more slowly than equipment used in EN13595 compliance testing, a scaling factor, developed from validation tests using this reference material was applied to all measured times.

In summary, circular samples of each material in the garment were retrieved from the garment. Samples were taken from locations where there was no crash damage. Samples were then attached to the sample holder using a hose clamp. Fibres were oriented either along the warp, weft or at 45 degrees to the warp and weft so that there were two samples tested at each fibre direction. Once the sample was prepared, the motor was then switched on and the abrasive belt brought up to the appropriate speed (8m/s). The sample holder with the fabric sample attached was then dropped onto the moving belt and the time taken for the fabric to abrade through was measured. As specified in the Standard procedure, after every 10 tests, a reference fabric was tested to adjust the abrasion time to account for wear of the abrasive belt during testing.

Analysis.
Data collected using the above procedure including the scaled time to hole measures was used to examine the relationship between the abrasion resistance performance of the clothing worn by the motorcycle riders. Each garment was classified by whether it was within the Level 1 abrasion resistant time requirements (yes/no), and for each material in each garment, an abrasion time was assigned. Binary logistic regression was performed to examine associations between abrasion time and occurrence of soft tissue injuries (excluding contusions) using general estimating equations to account for repeated measures. Materials which had not suffered an impact during the crash (no soft tissue injury or damage to the material) were excluded from the analysis. An injury risk curve was then developed. Development of the injury risk curves followed the recommended procedure outlined in ISO 18506 (International Organization for Standardization, 2014)

Results
Riders were commonly wearing jackets designed for motorcycle use (70.7%) and gloves designed for motorcycle use (64.1%), but were not as likely to be wearing footwear (38%) or pants designed for motorcycle use (35.9%). Gloves were the most frequently EU Standard certified clothing item, but represented only 6.5% of gloves worn. Only three percent of upper garments and one percent of lower garments were certified. Leather was the most common material used in footwear (63%), jackets (41.3%) and gloves (62.5%), while pants were most frequently made from medium weight materials (52.2%).

There were a total number of 633 damage locations identified during inspections or as noted by the participants. On average, upper garments had three specific locations of damage, while the lower garments, gloves and footwear had on average two points of damage. Abrasion damage was the most common type of damage (77.3%), and this remained consistent in all of the garment types. Tears were also relatively frequent (11.4%), but there was little evidence of burst (3.6%) or cut damage (1.3%). Extensive damage, where there was complete failure of the material so that the rider's skin became exposed, occurred in 117 of the 633 damage locations (18.5%). This consisted of 41 (16.1%) of cases of damage to upper garments, 56 (36.6%) cases of damage to lower garments, 16 (11.7%) cases of damage to gloves and 6 (4.4%) cases of damage to footwear.

Table 1 displays the number of garments found to have abrasion resistance within the Level 1 time requirements of the EU Standard using the scaled time to hole measures. For both upper and lower garments, the majority of the clothing worn by the riders in this study did not meet this requirement. There was one upper garment that was not designed for motorcycle use which was within the requirements of the Standard.

Table 1. Number of clothing items which were within the Level 1 time requirements specified in EN13595

Type of garment	**Clothing item**	**Within time n(%)**	**Not within time n(%)**
Designed for motorcycle use	Upper garment	5 (23.8)	21 (76.2)
	Lower garment	4 (36.4)	11 (63.6)
Not designed for motorcycle use	Upper garment	1 (7.7)	13 (92.3)
	Lower garment	0 (0)	47 (100)

The average time for the garments to abrade is shown in Table 2. Lower garments (0.98 sec) had a typically faster abrasion time than upper garments (1.25 sec).

Table 2. Average abrasion time for the different clothing items

Clothing item	**Abrasion time (sec)**	
	Mean (sd)	**Range**
Upper garment	1.25 (1.80)	0.02-8.96
Lower garment	0.98 (2.70)	0.02-20.36

The results of the binary logistic regression examining the association between the abrasion time of all materials and the occurrence of soft tissue injuries, is shown in Table 3. The dfbeta statistic was examined to determine if there were any values which should not be included in the analysis and no outliers were found. The results suggest that with an increase in abrasion time, the odds of a rider not being injured increased significantly (OR = 1.285, 95% CI: 1.035-1.595).

Table 3. Association between soft tissue injury and length of time taken for the clothing to abrade

Outcome variable	**Explanatory variable**	**Odds ratio**	**p-value**	**95% CI**
Rider uninjured	Abrasion time (s)	1.285	0.023	1.035-1.595

Discussion

This research has demonstrated that the probability of a rider *not* suffering a soft tissue injury increases significantly as the time taken for the clothing to abrade increases. This suggests there is significant benefit in increasing the time taken to abrade. It also indicates that the Cambridge Abrasion machine ranks clothing effectively in terms of the ability of the clothing to protect from soft tissue injuries in real world motorcycle crashes, even when modern materials are part of the sample. This means it may be an appropriate method to adopt for testing motorcycle clothing in Australia.

The majority of clothing worn by riders in this sample that was designed for motorcycle use did not fall even within the Level 1 abrasion resistance requirements of the Standard based on the results from this machine. This indicates a need to improve the quality of clothing sold to Australian motorcyclists and supports the need to adopt some form of quality control or consumer information program to help improve the quality of clothing worn by Australian riders, or at the very least allow riders to make informed decisions about the clothing they wear.

The main limitation of this research is that the absolute time to hole is generated using a scaling factor which has not yet been validated. This means the results presented in Table 3 may be overestimating the proportion of clothing that was within the requirements of the Level 1 criteria within EN 13595. All materials are currently being re-tested on equipment at Deakin University to confirm the preliminary results presented here, and to validate the scaling factor used. The results presented here should be viewed as preliminary. Another limitation is the relatively small sample size which prevents examination of the performances of the different materials.

Conclusion

This preliminary work found a significant association between likelihood of soft tissue injury and abrasion time, suggesting the Cambridge impact abrasion resistance test method is an appropriate method.

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