



Could wearing motorcycle protective clothing compromise rider safety in hot weather?



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ABSTRACT

Motorcycle protective clothing (PPE) effectively reduces the risk of injury in crashes, however in hot conditions many motorcyclists ride unprotected. Recent work found available motorcycle PPE to be thermally inefficient in hot weather with potential to cause significant thermal strain under average Australian summer conditions. The current study investigated the potential for the cognitive and psychophysical concomitants of thermal strain to compromise reaction times, mood and fatigue with potential consequences for motorcyclists' safety.

Method: Volunteers wearing motorcycle PPE participated in a 90 min trial (cycling 30 W) in 35 °C, 40%RH with overhead radiant heaters and a fan to simulate wind speed. Heart rate, core and skin temperature were recorded continuously. Reaction time and subjective ratings of thermal sensation and comfort, workload and mood were recorded at baseline, during rest breaks at 25 min intervals and on completion of the trial. Repeated measures analysis assessed each participant's performance against their own baseline.

Results: Core temperatures increased by 2 °C ($p < .0001$), skin temperatures (3 °C, ($p < .0001$) and heart rates (66bpm, $p < .0001$). Reaction times fluctuated 36 ms 8% ($p < .0001$) over the trial. Subjective workload increased 68% ($p = 0.001$) and mood deteriorated 33 points ($p < .0001$) including feeling less alert ($p = < .0001$), contented ($p = 0.001$) and calm ($p = 0.0004$). Multivariate repeated measures analysis found significant associations between core temperature and workload ($p = 0.01$), mood ($p = 0.001$) and reaction time ($< .0001$). Skin temperature and workload ($p = 0.02$), mood ($p = 0.01$) and reaction time ($< .0001$). Subjective ratings of temperature sensation and wetness discomfort were associated respectively with increased workload ($p = 0.0001$, $p = 0.004$), mood change ($p < .0001$, $p = 0.04$) and reaction time ($p < .0001$, $p < .0001$).

Conclusions: The physiological impact of wearing thermally inefficient motorcycle PPE in hot conditions could impair motorcyclists cognitive and psychophysical functioning and, potentially, their riding performance and safety.

These outcomes indicate an urgent need for manufacturers to develop motorcycle PPE that is effective and suitable for use, in hot conditions.

1. Introduction

Despite strong evidence that motorcycle personal protective clothing (PPE) reduces the risk and severity of injury in crashes, many motorcyclists ride unprotected particularly in hot conditions (Manzardo, 2006). Thermal discomfort has been identified as a key factor in non-usage, with riders being three times less likely to ride protected in hot conditions (Koch and Brendicke, 1998; de Rome et al., 2011c).

The question of whether thermal discomfort represents a potential safety risk for motorcyclists was first raised over twenty years ago but was not systematically investigated until recently (EEVC, 1993). In 2013, a majority of surveyed motorcyclists reported psychomotor skills

impairment associated with motorcycle clothing worn in hot conditions (Zwolinska, 2013). More recently, climate chamber trials demonstrated motorcycle clothing could impose significant thermal strain under average Australian summer conditions (de Rome et al., 2015a).

Protective clothing used in occupational contexts is often associated with thermal discomfort in hot conditions, due to the low vapour permeability of the garments which impedes the evaporation of sweat. The evaporation of sweat is an essential process for maintaining stable body core temperature (Holmer, 2006). If that process is restricted, deep body temperature can increase to the point of thermal strain with potentially serious health consequences (Hancock and Vasmatzidis, 2003; Walter and Carraretto, 2016). The European standards for motorcycle protective jackets and pants (CEN 13595:2002), provide specifications

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for the protective functions and ergonomic fit for mobility, but does not address thermal comfort (CEN, 2002).

The risks of thermal strain extend beyond the physiological impact on health with additional consequences for other aspects of human functioning and behaviour. There are established links between thermal strain, unsafe behaviour and injury in a range of occupational settings (Ramsey et al., 1983; Tawatsupa et al., 2013). Investigations of the mechanisms involved in these linkages leading to unsafe behaviour and injury have found a number of concomitant effects. There is evidence of thermal strain associated with impaired cognitive function in both simple and complex tasks, with complex tasks particularly vulnerable to extreme heat stress (Taylor et al., 2016). Thermal strain has also been associated with increased perceptions of workload (Qian et al., 2015) and with negative changes in mood states (Ely et al., 2013; Qian et al., 2015; Borg et al., 2017).

This study is a part of a program of research into the thermal management properties of motorcycle PPE and the psycho-physiological impact of poor thermal management when worn in hot conditions. The first study found poor thermal management properties, including very low vapour permeability (I_m), in each of a sample of ten widely-known brands of motorcycle jackets and pants tested on a thermal sweating manikin (de Rome et al., 2015b). The worst of those garments was used to investigate the physiological burden of wearing motorcycle PPE compared to street clothing. Under temperate conditions (Trials A and B, 25 °C, 40% RH) there were significant increases in skin temperature (> 2 °C) and heart rates ($+12$ beats min^{-1}) but not core temperature associated with the PPE (de Rome et al., 2015a). However substantial increases were observed in core and temperature and heart rate when ambient temperature was increased to 30 °C (Trial C) and again at 35 °C (Trial D). The focus of the current study was to investigate the potential consequences of such physiological thermal strain for rider safety.

2. Method

This was the last of the series of five trials (A–E) conducted with each participant acting as their own control to investigate the impact of wearing motorcycle PPE in hot conditions. Participants simulated the workload demands of riding a motorcycle in urban conditions by slowly riding an ergonometric bike set to 30 W (60 rev min^{-1}) (Monark Ergonomic 828E, Monark Exercise AB, Vansbro Sweden). Trials A–D focussed solely on physiological factors (as reported in de Rome et al., 2015a), whereas the fifth trial (E) was conducted to examine the impact of physiological strain on cognitive and psychophysical performance. Trials D and E were both conducted under 35 °C ambient temperature which represents the 86th percentile mean daily maximum summer temperature, in Australia's seven largest cities (BOM, 2011; de Rome et al., 2015a). All participants were provided with identical sets of clothing including helmet, gloves, boots and underwear for all five trials. The motorcycle jacket and pants used, was made from protective textile (600 Denier Polyester) with an inner, water-resistant liner and a comfort liner). The suit had been identified as having the worst thermal management of ten all-season suits tested on a thermal sweating manikin (de Rome et al., 2015b).

2.1. Participants

Due to delays in the conduct of this final trial, four of the 12 male volunteers who had completed Trials A–D were unavailable. The eight remaining participants represented a range of age groups and physical attributes with an average age 35.0 years [range 22–61], weight 82.6 kg [range 64.3–121.2], height 179.6 cm [range 168.5–188.5], sum of eight skinfold thicknesses 113.2 mm [range 46.5–276.0]. All were actively involved in regular physical exercise and were assessed as fit for the physiological demands of the study. Participants' pre-trial preparation included: consuming 15 mL kg^{-1} water the previous evening, high-



Fig. 1. Full motorcycle gear worn for thermal comfort tests.

carbohydrate, low-fat evening meal and breakfast, and abstaining from tobacco, heavy alcohol consumption or strenuous exercise for 12 h and from caffeine two hours prior to their trial. Prior to entering the climate-controlled chamber, participants' urine was tested to ensure they were in a well-hydrated, post-absorptive state and asked to consume as much as comfortably possible of 500 mL isotonic drink (10 mL kg^{-1}).

2.2. Environmental conditions

The conditions for Trial E were identical to Trial D (de Rome et al., 2015a). Ambient temperature was set to 35 °C and relative humidity to 40%. Sun and wind speed were simulated using three overhead, 500 W infra-red lamps and a large fan (velocity 30 km h^{-1}). Each trial comprised five minutes rest to establish baselines in the thermal chamber, then three segments of 25 min cycling followed by five minutes rest (See Fig. 1). The fan was turned off during each rest break to simulate the loss of cooling from wind speed when stationary. Participants completed computer-based tests during each of the four rest breaks.

2.3. Physiological and psychophysical measurements

Exposure variables were heart rate, deep body (core) temperature and skin temperatures, and subjective ratings of thermal (temperature and wetness) sensation and discomfort. Outcome variables were attention, workload and mood selected as proxies for predictors of safe riding performance.

Heart rate, deep body (core) temperature and skin temperatures were continuously monitored. Heart rate at 15-s intervals, from

ventricular depolarisation (Vantage NV, Polar Electro Sport Tester, Kempele, Finland). Temperatures were recorded at 15-s intervals using a 1206 Series Squirrel (Grant Instruments Ltd., Cambridge, U.K.). Mean skin temperature was derived from the weighted total of temperatures recorded from four sites — chest, forearm, thigh and calf (Ramanathan, 1964). Thermistors (Type EU, Yellow Springs Instruments Co. Ltd., Yellow Springs, OH, U.S.A.) were attached to shaved skin with a single layer of waterproof tape. Body core temperature was recorded using an ear moulded plug with a thermistor protruding one centimetre into the ear canal (FF mini thermistor, Edale instruments Ltd., Cambridge, U.K.). Participants wore correctly-sized open-face motorcycle helmets with comfort padding around the ears augmented with cotton wool to allow canal temperature to track oesophageal and central blood temperature without exposure to external air temperature (Taylor et al., 2012).

Self-reports of skin sensation and discomfort were collected on a modified Gagge rating scale at 15 min intervals during riding and at the end of each rest break (Gagge et al., 1967). Sensation scales for skin temperature and wetness ranged in 0.5 increments from 1.0-unbearably cold/dry to 13.0-unbearably hot/wet (High, 2013), where 7.0 was neutral. The comfort scales also in 0.5 increments ranged from 1.0-comfortable to 5.0-extremely uncomfortable. Sweat rates, clothing moisture retention and evaporation rates were determined by weighing all garments before and after each trial. Computer-based tests of attention and subjective ratings of work load and mood were conducted at each rest break using a touch-screen stylus and tablet. All tests were conducted using a hand-held Apple iPad Air 2. Participants were trained on each test prior to entering the climate chamber.

Attention, workload and mood were selected as outcome factors, having each been associated with increased crash risk in simulated driving scenarios (Stephens et al., 2013; Jallais et al., 2014; Paxion et al., 2015). Attention was assessed using Reaction Time (RT) (Cambridge Neuropsychological Test Automated Battery-CANTAB). The RTI test assesses attention as an executive function involving decision making and response time. The trial presents a semicircle of five large spots with a rest point at the bottom of the screen (See Fig. 2). Participants hold the stylus on the rest point until one of the five spots flashes yellow and then touch the spot which flashed. Reaction time is measured in milliseconds from the stimulus to the participant lifting the stylus. Movement time is measured in milliseconds from lifting the stylus to touching the target spot. Errors are tallied including non-response, premature movement and incorrect target. Participants were trained to a criterion of 5 out of 6 correct in a maximum of 40 attempts prior to entering the climate chamber. Scores for reaction and movement time were calculated for each participant as the difference in mean scores between at baseline and each rest point.

Workload was assessed using the Raw Task Load Index RTLX on a

21-point scale using a touch screen computer (Byers et al., 1989). The RTLX measures subjective workload by participants' ratings from high to low or good to poor on six dimensions: mental demand, physical demand, temporal demand (how rushed), performance, effort required and frustration/distraction. Overall workload scores are calculated as the average for each participant across the six dimensions. The task was to maintain riding speed at 60 rev. min⁻¹; participants were cautioned if their speed departed from that required.

Mood was assessed using the Visual Analogue Mood Scale (VAMS) which loads on three factors described as Alert, Contented and Calm (Bond and Lader, 1974). Participants rate how they feel 'right now' on 16 dimensions of mood using a visual analogue scale of 0–100. Mood is calculated as the mean of the sum of all dimensions overall and on each factor. Mood change is calculated as the mean of differences between baseline and each break.

2.4. Statistical analysis

Physiological and psychophysical data are presented in table and graph form using descriptive parameters (mean and standard deviation) to illustrate trends over the four stages of the experimental design.

Multivariate analysis was conducted using SAS Mixed procedure for repeated measures was used to test for linear associations between each participant's physiological and psychophysical data over the four test stages. Results are reported as F-values and significance for Type 3 tests of fixed effects.

Sensitivity analysis was conducted using paired t-tests to compare physiological and thermal sensation and comfort data from this trial with those for the same participants in the 35 °C trial (Trial D) conducted previously.

All data analysis was performed using SAS version 9.4 (SAS, 2013). Data was available for all participants on all measures. Ethics approval (HC15052) for this study was obtained from the Human Research Ethics Committee (University of Wollongong) in accordance with the National Health and Medical Research Council (Australia) and in compliance with the Declaration of Helsinki.

3. Results

3.1. Physiological measurements

Over the 90 min trial, there were substantial increases in all physiological indices: core temperature 2 °C ($F(4,5) = 57,923.8$, $p < .0001$), skin temperature 3 °C ($F(4,5) = 17,952.1$, $p < .0001$) and heart rate 66bpm ($F(4,5) = 191.4$, $p < .0001$).

Fig. 2 shows the distribution of physiological measures over time. Core temperature increased by half a degree (0.51 °C), in the first half hour and then more rapidly in the second (0.75 °C) and third (0.74 °C) stages. Heart rate (27 bpm) and skin temperature (1.9 °C) increased sharply in the first stage and continued to rise but at lower rates in the second and third stages. Skin temperature was slightly elevated and heart rate slightly lowered during each rest break.

Table 1 shows the mean and standard deviations averaged over each of the five-minute rest breaks. The sensitivity analysis showed these data to be consistent with results from the earlier study with no significant differences observed in physiological measures for Trail D (de Rome et al., 2015a). Mean core temperature was 38.3 °C (SD = 0.6) on completion of the trial.

Subjective ratings of skin sensation were consistent with their ratings in Trial D. Fig. 3 shows mean ratings and standard deviations (presented as bars) for skin sensation, where 10.0 equated to hot/wet and 11.0 to very hot/wet. At the first break (30–35 min), subjects were already approaching hot and wet with mean ratings of 9.6 ± 0.7 and wetness 9.4 ± 0.7 .

Fig. 4 shows ratings for discomfort and followed a similar trend to their physiological measures and were also consistent with ratings from

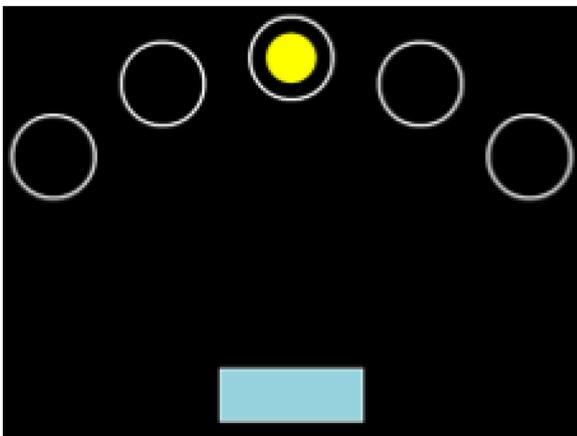


Fig. 2. Test screen for RTI five choice reaction time.

Table 1
Physiological measures at each break.

	Baseline		30–35 Rest		60–65 Rest		90–95 Rest		Post trial	
	Mn	Sd	Mn	Sd	Mn	Sd	Mn	Sd	Mn	Sd
Heart rate Bpm	80.2	13.5	107.0	16.0	132.3	24.2	141.1	27.5	142.8	23.7
Skin temp (°C)	34.7	0.7	36.6	0.7	37.3	0.6	38.0	0.5	37.1	0.7
Core temp (°C)	36.7	0.4	37.2	0.4	37.9	0.5	38.7	0.5	38.3	0.6

Trial D. Within the first 15 min of the trial, participants reported feeling slightly uncomfortable (2.0) on both dimensions. At the first rest break (30–35 min) their mean and standard deviation ratings for temperature (2.7 ± 0.5) and wetness (2.6 ± 0.6) were close to uncomfortable (3.0). At 60–65 min all were approaching very uncomfortable (4.0) for both temperature (3.4 ± 0.4) and wetness (3.3 ± 0.7). By the end of the trial (90–95 min) ratings were (3.8 ± 0.7) and (3.6 ± 0.9) respectively.

3.2. Cognitive function

Fig. 5 illustrates the distribution of scores on the Attention tests: reaction and movement time, number of premature moves and total errors at each rest break. Reaction times were initially stable then improved over baseline by 5% (20 ms) at 60–65 min. but slowed 8% (36 ms) at 90–95 min (F(4,22) = 106.7, p < .0001). Movement time initially slowed by 10% (28 ms) at 30–65 min, then remained constant (F(4,22.6) = 95.2, p < .0001). There was a distinct pattern to the distribution of errors with the majority occurring at the 30–35 and 90–95 min breaks, when reaction times were slowest (F(94,22.1) = 5.1, p = 0.01). The fewest errors occurred at 60–65 min when reaction speed had improved. Premature responses increased by 50% at 30–35 min but dropped below baseline for the remainder of the trial (F(4,21.9) = 3.0, p = 0.04).

3.3. Subjective workload

Participants' ratings of workload increased at each break (p = 0.001) and on each dimension (p ≤ .04). Fig. 6 shows the distribution of mean scores on overall workload (RTLX) and the six dimensions at each break.

3.4. Mood

Fig. 7 illustrates the means of the differences between ratings at baseline compared to each rest break. There were substantial changes at each stage and in overall mood (F(4,5) = 216.43, p < .0001) and on each dimension of mood compared to baseline. By the end of the trial, participants rated themselves as less alert (F(4,5) = 343.6, p < .0001), less contented F(4,5) = 37.49, p = 0.001, and less calm F(4,5) = 46.77, p = 0.0004).

3.5. Multivariate analysis

Table 2 provides the results of the repeated measures analysis of associations between physiological and psychophysical functions. Increasing body core temperature was associated with: subjective ratings of increased overall workload (F(1,8.0) = 10.64, p = 0.01) including performance (F(1,8.0) = 51.8, p < .0001), effort required (F(1,8) = 6.2, p = 0.04) and frustration/distraction (F(1,8.0) = 5.7, p = 0.04); with mood change (F(1,8.0) = 15.2, p = 0.005) including feeling less alert (F(1,8.0) = 19.6, p = 0.002) and less contented (F(1,8.0) = 11.9, p = 0.01); and with reduced attention including increased reaction times (F(1,8.0) = 1530.3, p < .0001), movement time (F(1,28.0) = 113.4, p < .0001) and premature moves (F(1,8.0) = 13.6, p = 0.01) compared to baseline (Fig. 8).

Skin temperature was associated with increased overall workload (F(1,8.0) = 8.4, p = 0.02) including performance (F(1,8.0) = 50.8, p < .0001) and effort required (F(1,8) = 6.1, p = 0.04); total mood change (F(1,8.0) = 12.5, p = 0.01) including feeling less alert ((F(1,8.0) = 16.7, p = 0.004); and less contented ((F(1,8.0) = 10.3, p = 0.01); and with reduced attention including increased reaction times (F(1,8.0) = 1419.4, p < .0001), movement times (F(1,8.0) = 130.5, p < .0001) and premature moves (F(1,8.0) = 14.2, p = 0.006) compared to baseline.

Heart rate was associated with increased performance (F(1,8.7) = 28.9, p = 0.001) and effort required (F(1,11.2) = 218.68, p < .0001); and reduced attention including increased movement time (F(1,9.0) = 74.0, p < .0001) and increased premature moves (F(1,10.2) = 12.1, p = 0.01). There were no associations between heart rate and mood change.

Table 3 presents the results of modelling for subjective ratings of thermal sensory experience as predictors of workload, mood and attention.

Ratings of higher skin temperature sensation were associated with increased overall work load (F(1,9.4) = 41.2, p = 0.0001) including mental (F(1,8.1) = 14.3, p = 0.01) and temporal demand (F(1,10.0) = 18.0, p = 0.002), performance (F(1,10.2) = 23.5, p = 0.001) and frustration/distraction (F(1,9.3) = 88.1, p < .0001), total mood change (F(1,8.0) = 59.9, p < .0001) including reduced alertness (F(1,8.1) = 11.2, p = 0.01) and contentedness (F(1,7.6) = 10.5, p = 0.01), and reduced attention including increased reaction time (F(1,15.7) = 1195.7, p < .0001) and movement time (F(1,7.8) = 110.9, p < .0001).

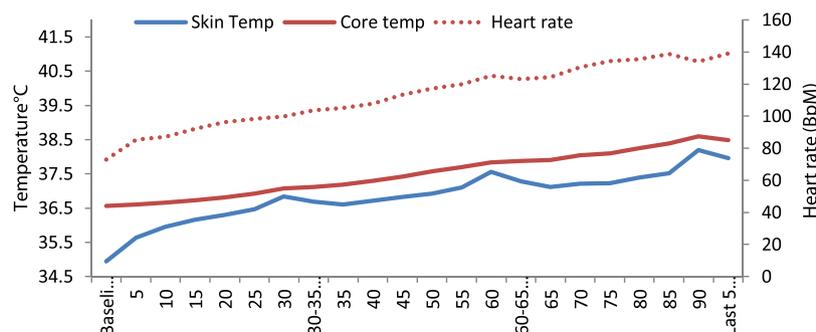


Fig. 3. Physiological measurements (Mn) at five-minute intervals Subjective comfort.

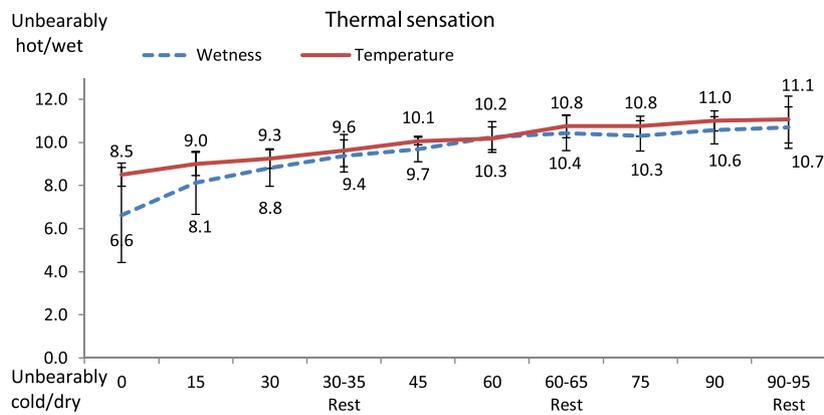


Fig. 4. Thermal and wetness sensation mean ratings with standard deviations.

Increasing skin temperature discomfort was associated with: increased work effort required ($F(1,8.2) = 19.4, p = 0.002$), reduced alertness ($F(1,7.1) = 28.7, p = 0.001$) reduced contentedness ($F(1,7.8) = 7.0, p = 0.03$).

Ratings of greater wetness sensation were associated with higher temporal demand ($F(1,8.9) = 8.7, p = 0.02$) and performance ($F(1,11.7) = 8.1, p = 0.02$), reduced alertness ($F(1,5.9) = 42.1, p = 0.001$) and contentedness ($F(1,7.0) = 6.1, p = 0.04$), and increased reaction times ($F(1,6.9) = 63.2, p < .0001$) and premature moves ($F(1,8.4) = 13.4, p = 0.01$)

Increasing wetness discomfort was associated with increased overall workload ($F(1,6.9) = 17.4, p = 0.004$) and frustration/distraction ($F(1,8.1) = 680.3, p < .0001$), increased mood change ($F(1,9.1) = 6.0, p = 0.04$) including reduced alertness ($F(1,6.9) = 39.1, p = 0.001$), contentedness ($F(1,9.4) = 23.1, p = 0.001$) and calmness ($F(1,15.6) = 9.3, p = 0.01$) and with increased reaction times ($F(1,9.5) = 289.0, p < .0001$) and total errors ($F(1,6.5) = 14.8, p = 0.01$).

4. Discussion

Initial research had established the potential for motorcycle protective clothing to restrict human thermoregulatory function sufficiently to cause severe thermal strain in hot conditions (de Rome et al., 2015a). This study is the first to investigate the psychophysical concomitants of thermal strain for motorcyclists associated with protective clothing. The results found evidence of impaired reaction times, increased workload and deteriorating mood state associated with increasing physiological thermal load and sensory discomfort.

The results are consistent with other findings of negative associations between thermal strain and cognitive performance (Berg et al., 2015; Schmit et al., 2016; Walter and Carraretto, 2016), perceptions of exertion and workload (Dunne et al., 2013; Jazani et al., 2016) and

mood (McMorris et al., 2006; Qian et al., 2014) in other contexts. The apparently contradictory distribution of reaction times observed in this study may be explained by the complex relationship between core temperature and cognitive function. Current thinking describes this as an inverted U-shaped curve, with cognitive function improving until core temperature reaches a threshold $\sim 38.5^\circ\text{C}$, then declining from $\sim 39.0^\circ\text{C}$ (Schmit et al., 2016). Such a curve is consistent with the reaction times recorded in this study, which peaked at the 60 min break, when average core temperature reached $37.8^\circ\text{C} (\pm 0.4)$ but had declined by the next break at 90 min when core temperatures reached $38.5^\circ\text{C} (\pm 0.6)$.

The factors of interest – reaction time, mood and workload – were selected as validated indicators of functional impairment that may compromise riding safety. They provide simple indices with face validity for estimating the potential detriment to motorcyclists' riding performance and safety. The associations between subjective ratings of sensory discomfort and the evidence of deteriorating reaction times, mood and perceptions of workload are important signals which could alert motorcyclists when their riding performance may be impaired. Reaction time and subjective workload have been identified as contributing factors in the number of collisions in simulated driving scenarios (Paxion et al., 2015). Negative mood has also been associated with increased risk taking in a simulator study where angry drivers responded differently to potential hazards, were slower to detect atypical hazards, underestimated inherent risks and took longer to take corrective action (Stephens et al., 2013; Jallais et al., 2014). While these have not yet explicitly been linked to crash risk in motorcyclists, there is no reason to expect these same associations between increased reaction times, workload, mood, discomfort and crash risk for drivers would be different for motorcyclists.

The ability to control environmental inputs by use of a climate-controlled chamber was the key strength of this study. As was the

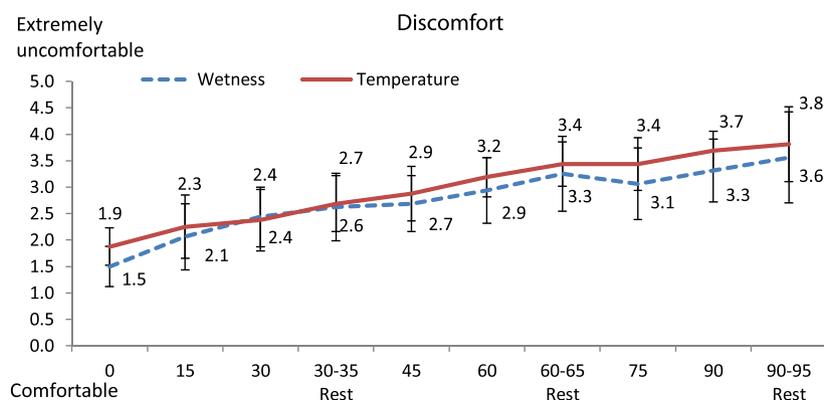


Fig. 5. Thermal and wetness comfort mean ratings with standard deviations.

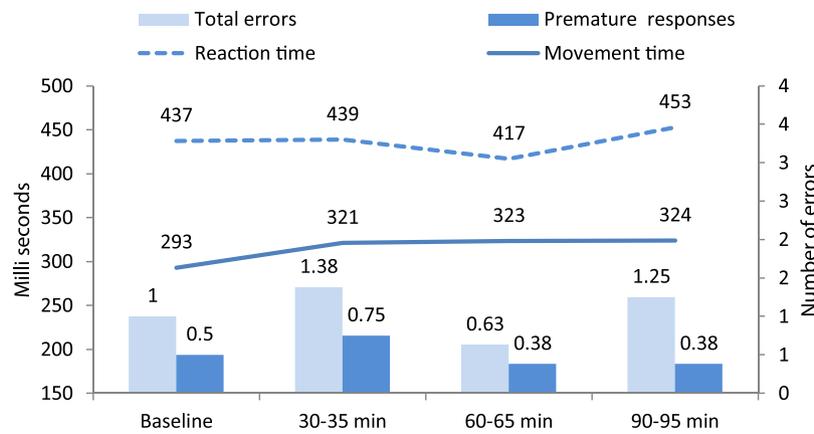


Fig. 6. Mean scores on tests of attention.

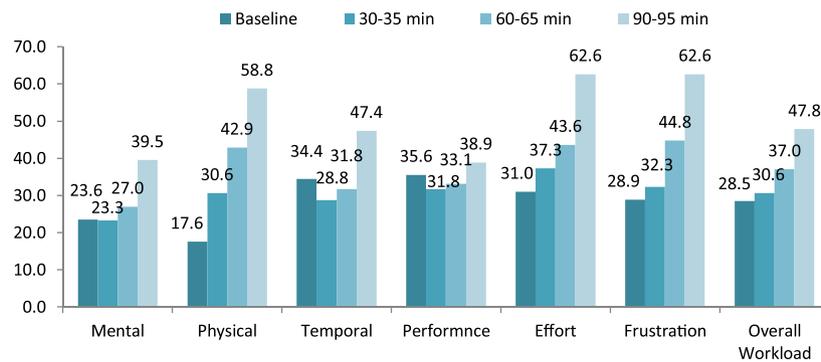


Fig. 7. Perceptions of load overall (RTLX) and on each dimension.

Table 2
Association between physiological and psychophysical measures.

Outcome ^a	Core temperature		Skin temperature		Heart rate	
	F value	Pr > F	F value	Pr > F	F value	Pr > F
Work load						
Overall work load	10.64	0.01	8.43	0.02	0.74	0.40
Mental demand	1.30	0.29	1.12	0.32	0.97	0.34
Physical demand	1.03	0.34	0.95	0.36	1.88	0.20
Temporal demand	4.26	0.07	3.41	0.10	2.00	0.18
Performance success	51.77	< .0001	50.81	< .0001	28.95	0.00
Effort required	6.17	0.04	6.07	0.04	6.58	0.03
Frustration/distraction	5.73	0.04	3.06	0.12	0.07	0.80
Mood						
Overall mood	15.16	0.00	12.53	0.01	3.13	0.11
Alert	19.62	0.00	16.67	0.00	3.32	0.09
Contented	11.58	0.01	10.31	0.01	3.86	0.08
Calm	4.67	0.06	4.56	0.07	2.50	0.15
Attention						
Reaction time	1530.28	< .0001	1419.37	< .0001	0.01	0.91
Movement time	113.38	< .0001	130.51	< .0001	74.02	< .0001
Premature moves	13.59	0.01	14.15	0.006	12.13	0.006
Total errors	1.92	0.20	1.9	0.205	1.49	0.25

^a Type 3 tests of fixed effects for repeated measures over sequential stages.

availability of participants acclimatized to working in hot conditions and mostly fitter than the general population (de Rome et al., 2015a). These participants were able to complete these very arduous trials, whereas thresholds for hyperthermia may have been reached earlier and with greater severity in a more sedentary or less fit sample. Vulnerability to thermal strain can vary according to individual differences in physiology such as weight, cardiovascular fitness and heat acclimatization, as well as transitory factors such as fatigue or ill-health (Cuddy et al., 2013; Kenny et al., 2013; Mora-Rodriguez et al., 2013).

A limitation of the study was the loss of four of the 12 participants who had completed the first four trials. The option of introducing alternative participants was considered inappropriate as they would not have been acclimatized to the trial conditions and may have introduced other unknown factors. While the smaller sample did represent less power, the impact was limited due to the study design using each participant as their own control over the five thermal condition trials. The sensitivity analysis showed no differences in physiological measures or subjective ratings of thermal comfort, between the main and

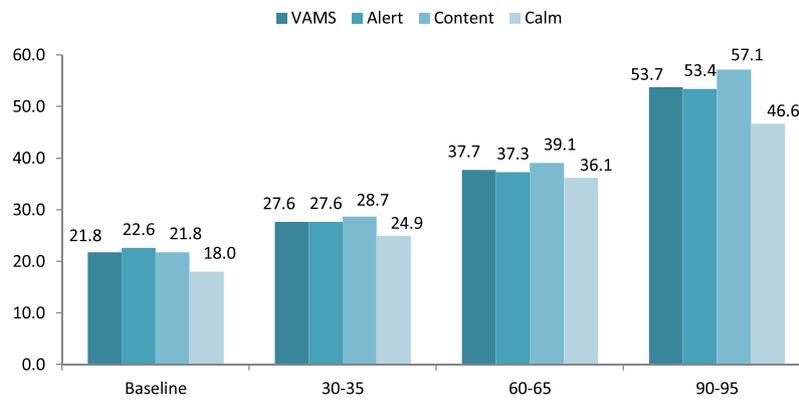


Fig. 8. Mean differences in ratings of mood (VAMS) and dimensions of Alert, Contented and Calm.

Table 3

Associations between subjective ratings of thermal sensory experience and workload, mood and attention.

	Temperature		Wetness					
	Sensation	Discomfort	Sensation	Discomfort		F Value	Pr > F	
	F Value	Pr > F	F Value	Pr > F	F Value			Pr > F
Raw Task Load Index								
Workload	41.2	0.0001	–	–	–	–	17.4	0.004
Mental demand	14.3	0.01	–	–	–	–	–	–
Physical demand	–	–	–	–	–	–	–	–
Temporal demand	18.0	0.002	–	–	8.7	0.02	–	–
Performance	23.5	0.001	–	–	8.1	0.02	–	–
Effort	–	–	19.4	0.002	–	–	–	–
Frustration	88.1	< .0001	–	–	–	–	680.34	< .0001
Visual Analogue Mood Scale								
Overall mood	59.9	< .0001	–	–	–	–	6.0	0.04
Alert	11.2	0.01	28.7	0.001	42.1	0.001	39.1	0.001
Contented	10.5	0.01	7.0	0.03	6.1	0.04	23.1	0.001
Calm	–	–	–	–	–	–	9.3	0.01
Choice Reaction time								
Reaction time	1195.7	< .0001	–	–	63.2	< .0001	289.0	< .0001
Movement time	110.9	< .0001	–	–	–	–	–	–
Premature moves	–	–	–	–	13.4	0.01	–	–
All errors	–	–	–	–	–	–	14.8	0.01

current study trials at 35 °C, which was the condition under investigation here. The primary limitation to the study was that we were unable to compare these results with those under cooler temperatures (25 °C, 30 °C) or when wearing non-motorcycle clothing (de Rome et al., 2015a).

The study design ensured the motorcycle PPE was tested under worst-case conditions, on the principle that if thermal strain was not demonstrated, then it would be less likely in any real-world situation. Accordingly, participants were required to ensure all fastenings including ventilation ports were closed. There is strong evidence to support the efficacy of local ventilation in protective clothing, however this is dependent on forced convection and user movement (Chinevere et al., 2008). A motorcyclists' riding position is essentially static so ventilation is dependent on convection from wind speed, which will be insufficient in slow or stationary traffic. Under slow traffic conditions, vapour permeability may be the only available mechanism to effectively promote evaporative heat loss (Dai and Havenith, 2016). The study design took this into account with the fan simulating wind speed being turned off during the 5 min rest breaks.

Poor thermal management associated with protective clothing is a challenge for many industries, but motorcycling may be considered a special case. In most occupations, protective clothing is worn only for the duration of exposure to specific hazards, such as fires, hazardous spills or military encounters. This is not the case for motorcycling,

which is a form of transport rather than an inherently hazardous occupation. In practice the primary function of motorcyclists clothing is physiological comfort in terms of protection from heat, cold and wetness.

In hot climates, such as Australia, where ambient temperatures are often close to body temperature, there is little safety margin for increased thermal burdens imposed by clothing. However, the study conditions of 35 °C and 40%RH, are not unique to Australia and are experienced or exceeded in many other countries where motorcycles are used. In addition, whereas the motorcycle PPE used in this study was selected as having the worst thermal management of ten motorcycle suits from internationally distributed brands, it should be noted that none of the suits tested achieved even the lowest acceptable score ($I_m = 0.4$) on the Relative Vapour Permeability scale from 0 to 1.0 (de Rome et al., 2015b). Given evidence that many motorcyclists ride unprotected in hot weather, it seems likely that many other motorcycle PPE products also lack effective thermal management (Manzardo, 2006; de Rome et al., 2011c).

5. Conclusions

The outcomes of this study provide strong evidence that thermal comfort is more than a mere sensory preference but is a potential safety issue for motorcyclists. The results illustrate how thermally inefficient

motorcycle PPE, worn in hot conditions, may impair motorcyclists' cognitive and psychophysical functioning and potentially their riding performance and safety.

In the context of evidence that much of the motorcycle PPE available internationally is thermally unsuitable for use in warm climates, these results have important implications for riders and the motorcycle clothing industry globally.

Riders need to be aware of the risks associated with heat discomfort and hyperthermia. Safety programs could promote riders' awareness of the features of thermally efficient garments and how to recognise and respond to the signs of thermal stress and impaired functional responses.

Industry should be encouraged to recognise the importance of effective thermal management design and consideration given to its inclusion as a standard requirement for motorcycle protective clothing. The challenge for industry will be to provide clothing that is ergonomically suitable for operating and riding a motorcycle under all conditions, in addition to protecting the rider from injury in the event of a road crash.

There is a need for more research into the development of garments that allow heat and sweat to continue to be expelled when air-forced convection is unavailable. Further research is also required to determine the optimal locations and design for ventilation ports, that do not compromise the integrity of garments under crash conditions.

The development of thermally effective PPE is of critical importance as the volume of motorcycles in the world's fleets increases with corresponding numbers of road crash casualties (WHO, 2017).

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