WHAKARATONGA IWI

FIRE EMERGENCY NEW ZEALAND

Thermal and Carcinogenic Consequences of Live Fire Training on National Training Centre-Based Trainers

THERMAL AND CARCINOGENIC CONSEQUENCES OF LIVE FIRE TRAINING ON NATIONAL TRAINING CENTRE-BASED TRAINERS

Toby Mündel and Samuel Keer

Report to Fire and Emergency New Zealand

September 2022

Fire and Emergency New Zealand Research Report Number 190
ISBN Number 978-1-92-728755-2
ISSN Number 2703-1705

Mündel, Toby and Keer, Samuel (2022). Thermal and Carcinogenic Consequences of Live Fire Training on National Training Centre-Based Trainers. Report prepared for Fire and Emergency New Zealand.

This research was commissioned by Fire and Emergency New Zealand and undertaken by independent researchers. Publication does not indicate Fire and Emergency New Zealand's endorsement of the findings or recommendations.

Acknowledgements

The research team appreciates the assistance of all Fire and Emergency New Zealand personnel involved, directly or indirectly, but would specifically like to thank the following: National Operations Advisor (Carcinogen Control); the project reference group members; instructors and staff at the National Training Centre.

Table of Contents

Research Summary

Rationale

Live fire training instructors are regularly exposed to elevated levels of carcinogens as a consequence of conducting compartment fire training. The standard personal protective equipment (PPE) they are provided with offers some protection; however, studies indicate that this PPE system does not stop carcinogens from penetrating their Level 2 PPE (outer layer bib overalls and jacket) and depositing on their skin. Studies have shown that layers of clothing can act like a barrier by limiting carcinogens from penetrating down to the skin, but it is not clear what type of fabric would be most suitable for the layer closest to the skin: cotton or wool. The current study assessed the ability of a woollen underlayer to prevent particulates from reaching the skin, whilst also understanding whether this impacts on heat strain experienced, which may arise from using these PPE items.

Method

Six instructors at the National Training Centre were monitored on four consecutive afternoons of a live fire career recruit training week. Core body temperature (T_{core}, measured by an ingestible pill) was collected during each exposure and estimates of sweat loss and fluid intake were made for each training exposure, whilst dermal (skin patch, 122 total) and biological (urines, 102 total) samples were collected from the trainers throughout each training session.

Key Findings

- Instructors begin their live fire exposures hypohydrated (less than optimally hydrated) the majority of the time
- Instructors have higher sweat rates than fluid intake during live fire exposure, but regain this body water by the start of the following day's exposure
- The combination of compartment heat, PPE and activity causes T_{core} to rise quickly during an exposure, although peak T_{core} does not exhibit dangerous levels
- It is likely that the instructors who begin the day more hypohydrated will also register the highest T_{core} during an exposure
- Cell managers will likely achieve higher peak T_{core} with concurrent high sweat rates due to 'mucking out' (cleaning out of partially burned pallet wood from training cell). Therefore, cell managers are potentially at greater risk for heat strain than cell trainers
- Instructors are exposed to polycyclic aromatic hydrocarbons (PAHs, the primary carcinogens of concern) during live fire training, including safety officers, as shown by detectable levels of PAHs on patch samples and increased post-fire compared to pre-fire hydroxy-PAHs (OH-PAH, metabolites of PAHs) levels in urine
- Results suggest merino undergarments and protective hoods reduce dermal exposures, and their use should be facilitated/encouraged as they do not negatively influence T_{core} or sweating; however, due to issues with the reliability of the skin patch data, further research would be beneficial

- PAH levels were highest on average at the neck, indicating the importance of correct donning/doffing procedures for protective hoods

Introduction

Background

Live fire instructors are regularly exposed to elevated levels of carcinogens as a consequence of conducting compartment fire training (Fent et. al. 2019; Kirk and Logan 2015; Laitinen et. al. 2010; Wingfors et. al. 2017). The standard personal protective equipment (PPE) they are provided with offers some protection; however, studies indicate that this PPE system does not stop carcinogens from penetrating their Level 2 PPE and depositing on their skin (Kirk and Logan 2015; Wingfors et. al. 2017). Due to their multiple, long-duration exposures (by comparison to an operational firefighter), they are the most vulnerable firefighters in Fire and Emergency New Zealand in terms of risk from carcinogen exposure.

Studies have shown that layers of clothing can act like a barrier by limiting carcinogens from penetrating down to the skin (Wingfors et. al. 2017). More specifically, wearing a layer of clothing, such as a Level 1 PPE (t-shirt and pants, worn under stage 2 outer wear), significantly reduces skin deposition. It is not clear what type of fabric would be most suitable for the layer closest to the skin. Both cotton and wool are highly hydrophilic (i.e., soak up water). Cotton may form a 'water barrier' by absorbing sweat which fills the pores in the fabric. Similarly, wool can 'wick' sweat and oil from the skin which may reduce carcinogen deposition on the skin and instead hold the carcinogens on the wool itself. Firefighters often wear a tight-fitting cotton underlayer (e.g., cotton pants and cotton shirt) but this may decrease the ability of the Level 2 PPE to dissipate heat. Evaluating a woollen underlayer would help to clarify which is more effective at preventing carcinogen deposition while maximising heat dissipation.

Fire and Emergency is interested in research to evaluate the ability of the woollen underlayer to prevent particulates from reaching the skin, whilst also understanding whether this impacts other health risks, such as an increase in heat strain, which may arise from using these PPE items.

Research Purpose

Fire and Emergency commissioned Massey University to undertake this research to determine the thermal and carcinogenic consequences of National Training Centre live fire instructors conducting compartment live fire training.

The research project had two specific objectives:

1. Determining the thermal consequences of live fire training by:
    - Collecting core body temperatures via ingestible pill during exposure
    - Estimating sweat loss and fluid consumed via semi-nude body weight measures before/after exposure and monitoring and correcting for fluid volume consumed
2. Determining the carcinogenic consequences of live fire training by:
    - Collecting dermal (skin patch) and biological (urine) samples from trainers following exposure

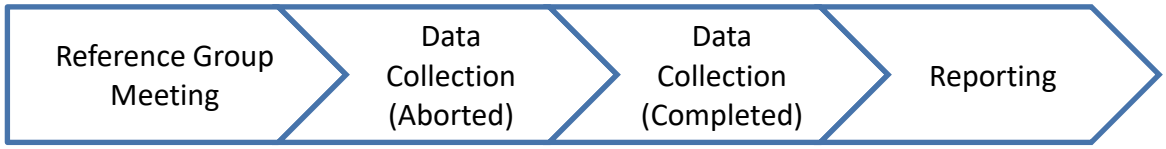
Methods

Research Design

Ethics

This research was conducted under Massey University Human Ethics Committee (MUHEC) guidelines, with the project approved by MUHEC: Southern A (Application Number SOA 21/20).

The dual objectives of this project were achieved through the following key steps:



Reference Group Meeting

Following initial dialogue and discussion with FENZ, the Reference Group met at National Training Centre in March 2020 to allow rich discourse between all key stakeholders and further/final design of the project. The arrival of COVID-19 into Aotearoa New Zealand delayed/postponed the commencement of data collection.

Initial/Aborted Data Collection

Data collection commenced on Tuesday, August 17, 2021, but a snap national lockdown due to COVID-19 meant that only 1 day of testing was completed, with all researchers and Fire and Emergency personnel sent home.

Revised/Completed Data Collection

Data collection commenced on Tuesday, November 9, 2021, and was completed on Friday, November 12, 2021.

Reporting

Separate presentations were prepared and given via Zoom for the thermal (Mündel, December 2021) and carcinogen (Keer, June 2022) data, followed by a combined written report.

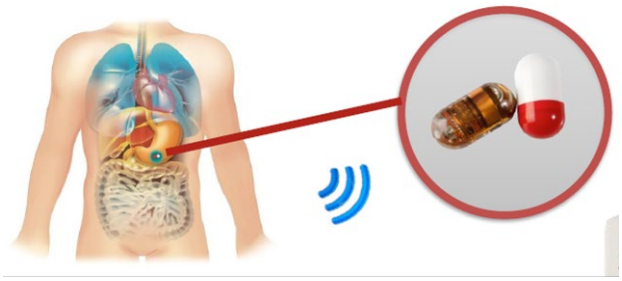
Sampling strategy

Six instructors conducting live fire training scenarios took part in exposure/thermal monitoring on all 4 training days. Three instructors had roles as cell managers and three as trainers, with these roles maintained across the 4 days. All instructors wore merino undergarments under their outer protective wear on days 1 and 2 for the duration of the training scenario, and only their undergarments on days 3 and 4. Trainers completed a pre-sampling questionnaire before each training session, which included questions on the consumption of barbequed food/other factors which may influence urinary PAH levels before being prepared for hydration and thermal measures (see below).

Thermal

Each morning at 7 am, instructors ingested a BodyCap™ pill for measurement of the gastrointestinal tract temperature. Temperatures were automatically recorded onto the pill and then were downloaded at the end of the day through the recorder. The accuracy of the pill is 0.2°C and measurements were recorded every minute.

Figure 1. BodyCap™ gastro-intestinal pill and monitor



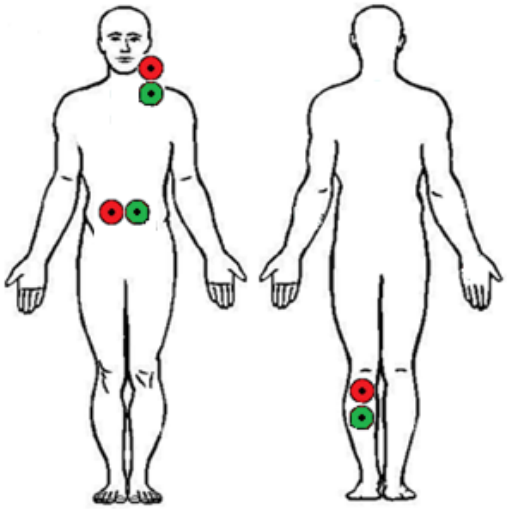
Hydration

Instructors weighed themselves semi-nude (underwear) in private at the start and end of the training using a portable scale (Jandever), accurate to 10g. Fluid intake was monitored by providing instructors with pre-measured bottles of their preferred drink (either water or ice slushie) for the duration of the training.

Dermal and Biological Samples

To estimate exposure to polycyclic aromatic hydrocarbons (PAHs), sets of 3 patches (40mm diameter absorbent cellulose discs ['Whatmann benchkote'] with an adhesive but removable backing) were placed directly onto each of the instructors' skin at locations where entry of PAHs past Level 2's was possible (behind the knee, the navel and the side of neck). To evaluate the protective effectiveness of the standard protective hoods (always worn) and merinos (worn on days 1 and 2) against dermal deposition of PAHs, additional patch sets were worn on the surface of the garments but offset to those on the skin (to avoid occluding those underneath – see figure 2 below). In addition, a dummy instructor was constructed and used as a positive control; this consisted of a safety helmet attached to a telescopic stand set at approximately chest height (head height of instructor in a semi-prone stance) with a clean protective hood stretched over the helmet and sealed – one patch was placed against the helmet underneath the protective hood and a second on the hood surface (again, offset from the one underneath). This dummy was deployed for each of the 4 training sessions (8 patches total). Finally, safety officers (indirectly involved in the scenario - positioned outside of the training cell but in reasonably close proximity to the entry and not wearing level 2's) were asked to wear a single patch at the same neck patch site as the trainers (2 patches total from 2 training sessions).

Figure 2. Dermal patch site locations (skin surface = red, merino surface = green)



All instructors were asked to provide one urine sample before commencing each training session ('pre-burn'), and four samples during and after the session ('post-burn'). Pre-burn samples were collected within 1.5 hours before commencing each session, and post-burn samples were collected of each of the four urine voids made after commencing the session (whenever these occurred). Each participant was provided with a cool bag containing collection cups and an ice pack, and all samples were transferred to a freezer (-20^{o}C) on-site

as soon after collection as possible (where they were stored for the duration of the training week, before being transported on ice back to Massey Wellington).

All patch samples were shipped on ice to Queensland Forensic and Scientific Services, Queensland Health, for extraction and subsequent analysis by liquid chromatography/mass spectrometry (LC/MS). Patch extracts were analysed for a comprehensive panel of PAHs, with an emphasis on those which are generally most abundant /with the greatest potential relative carcinogenicity (see appendix for complete list). The method detection limit for all PAHs was 10 nanograms per patch (ng/patch). All urine samples were shipped to the Queensland Alliance for Environmental Health Sciences, University of Queensland and analysed using a similar method for a range of PAH metabolites (hydroxy-PAH, or OH-PAH). Target OH-PAHs and respective method detection limits (MDL) are shown in table 1. Urine strength (required for standardisation of OH-PAH levels) was determined using specific gravity (SG).

Data Analysis

Thermal and hydration results are reported as mean±SD and were analysed using one-way analysis of variance and paired *t*-tests where appropriate. Pearson's correlation coefficients were calculated to reveal the direction and strength of any potential relationships between variables.

Dermal patch results are presented as the sum of all PAHs detected on the patch, and individual isomers are combined into a single category for urinary OH-PAH levels (e.g. 'hydroxynaphthalene'). Due to issues with data accuracy (see below), only patches with detectable levels of PAH were included when calculating means and standard deviations. Urinary OH-PAH levels were corrected for specific gravity (urine strength), and where levels of individual compounds were below the method detection limit (MDL), half the limit was used for analytical purposes. Geometric mean OH-PAH concentrations were presented, as they are considered more appropriate for evaluating exposure monitoring data (Seixas et al. 1988). Also, due to the small sample sizes involved, analysis of both patch and urine samples were limited to descriptive statistics and evaluation of correlations between exposure measures (i.e. patch vs. urinary levels).

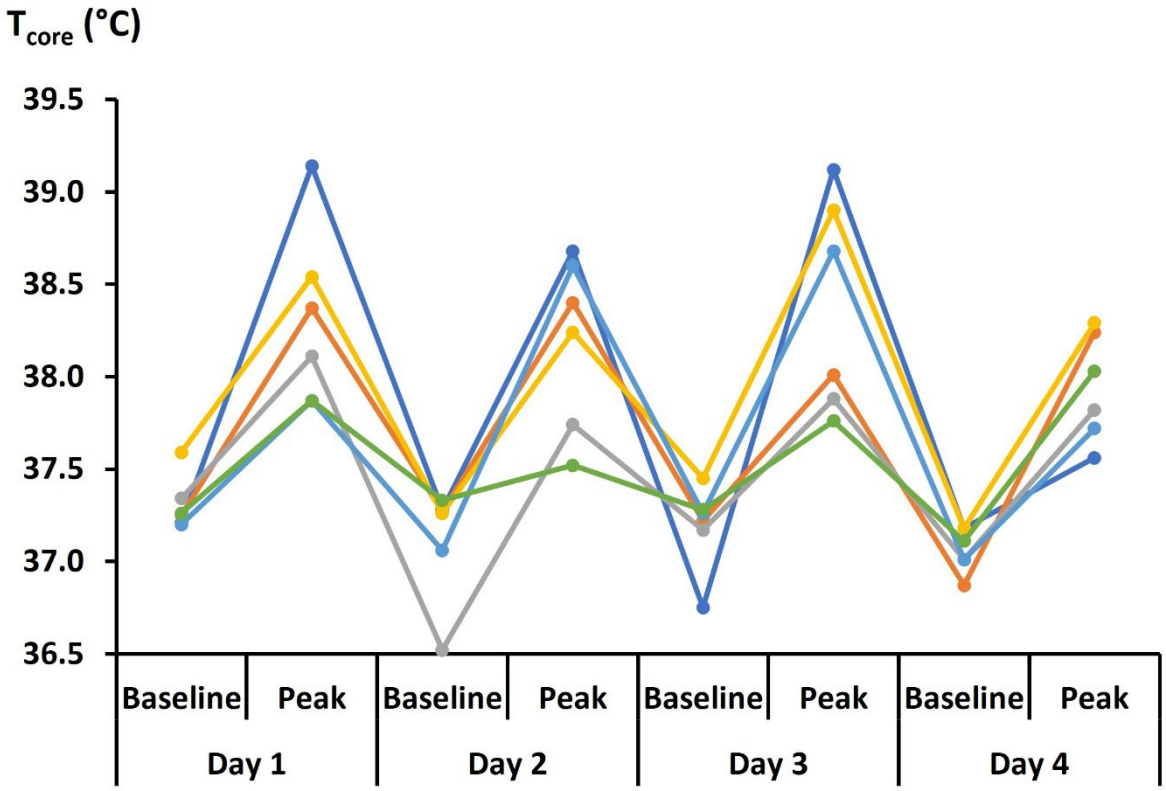
Results

Live fire training lasted 170, 150, 160 and 150 min on the first through to the fourth day of data collection, respectively. The average ambient temperature within the compartments registered 250±31°C whilst peak ambient temperatures registered 269-324°C.

Thermal

T_{core} at the start of each live fire training was not different (p=0.232) between days (37.2±0.2°C), although this increased (p<0.001) during each live fire training by 1.0±0.5°C to a peak of 38.2±0.5°C. Level 1 merinos did not affect this change in T_{core} (p=1.000).

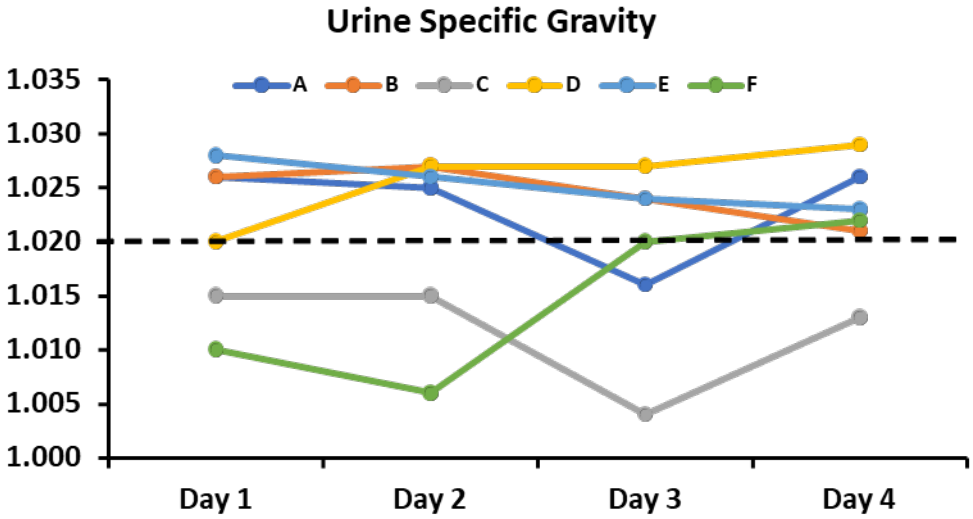
Figure 3. Individual baseline and peak T_{core} across all four days of live fire training. Days 1 and 2 instructors wore merino Level 1's, days 3 and 4 they did not.



Hydration

USG at the start of each live fire training was not different (p=0.759) between days (1.021±0.01), although hypohydration – defined by USG > 1.020 (Sawka et al. 2007) – was evident on 15 out of 24 occasions.

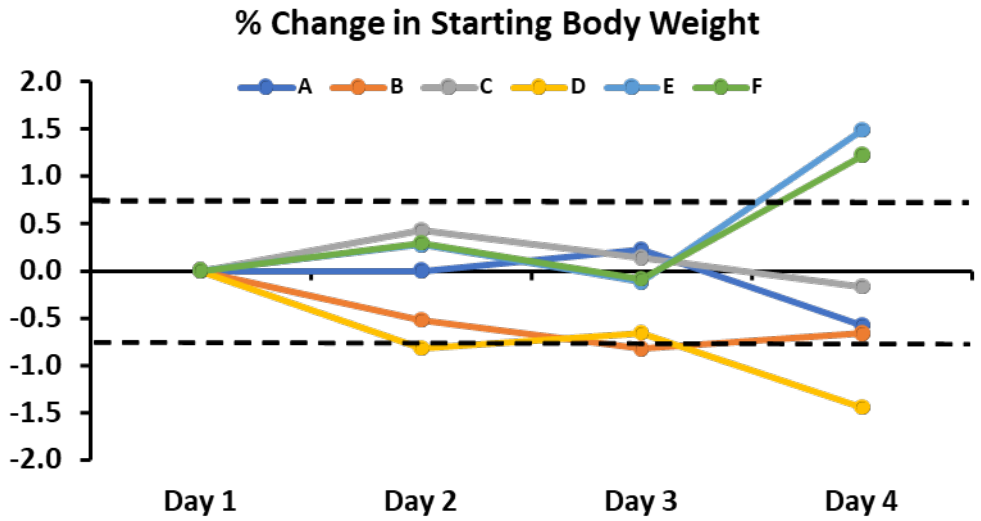
Figure 4. Individual USG values at the start of each live fire training, with the dashed line representing the cut-off for hypohydration (> 1.020). Days 1 and 2 instructors wore merino Level 1's, days 3 and 4 they did not.



Sweat loss during each live fire training was not different (p=0.783) between days (554±221 ml·h^{-1} or 0.7±0.6% body weight), with Level 1 merinos not affecting this (p=0.750). Fluid intake during each live fire training was not different (p=0.649) between days (328±181 ml·h^{-1})), with Level 1 merinos not affecting this (p=0.291).

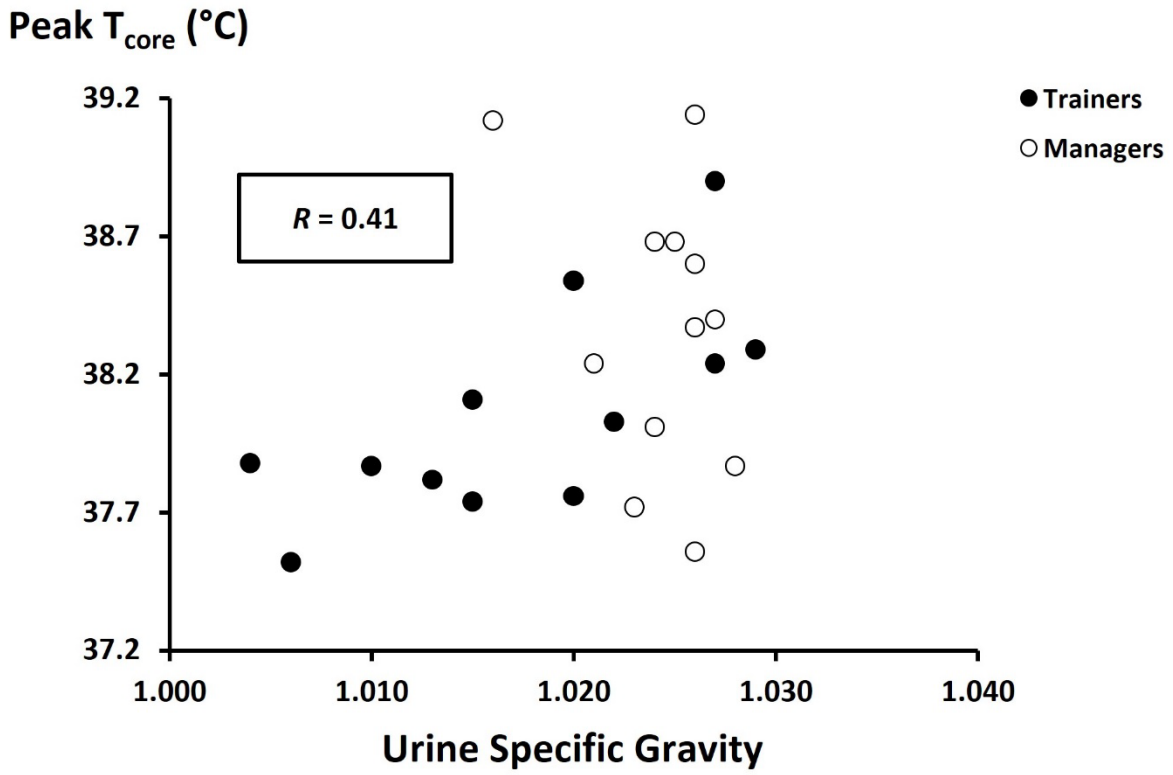
Natural daily fluctuations in body weight are typically 0.7% (Cheuvront et al. 2004). Instructors displayed no difference in their daily starting body weight (p=0.877), which fluctuated by only 0.1±0.7% indicating that they had regained any/all fluid loss from the previous day's live fire training by the following day i.e., no carry-over effect.

Figure 5. Individual percent change in starting body weight at the start of live fire training, with dashed lines representing ±0.7% typical daily fluctuations. Days 1 and 2 instructors wore merino Level 1's, days 3 and 4 they did not.



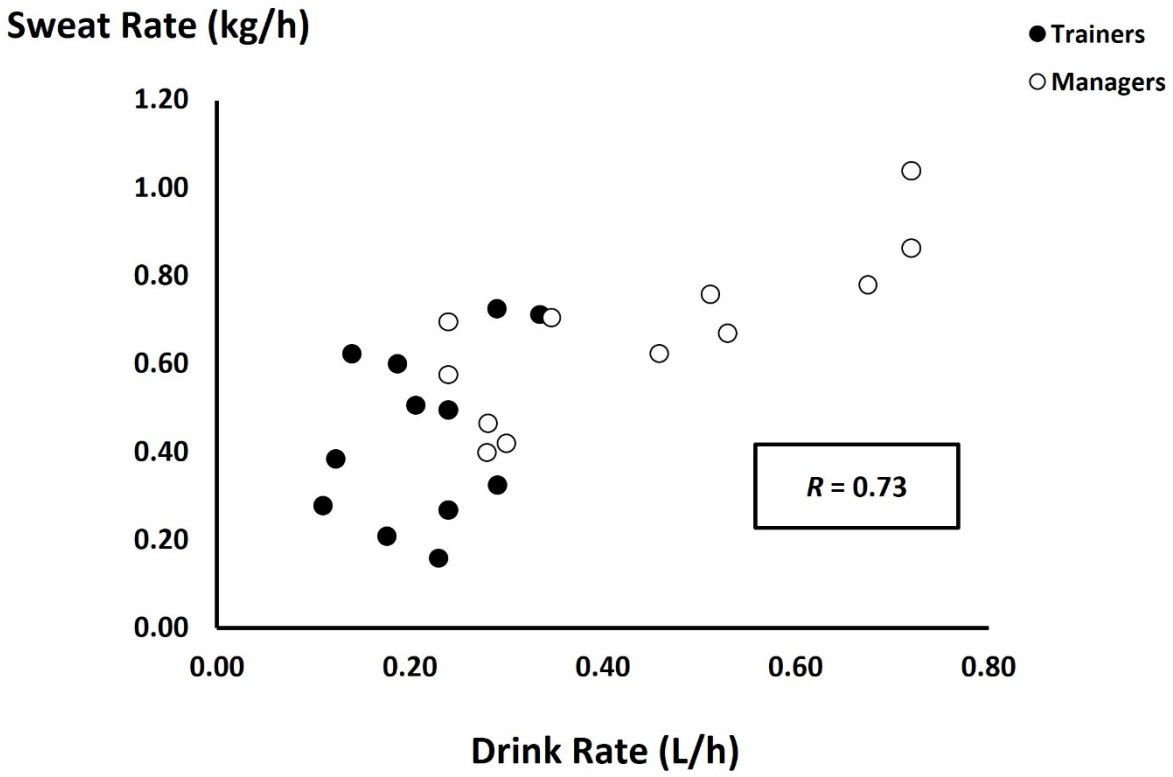
A medium association (*R*=0.41) was found between an instructor's peak T_{core} and starting hydration (urine specific gravity), with cell managers at the upper end and cell trainers at the lower end. Therefore, the more dehydrated an instructor begins the shift the higher the thermal strain encountered will likely be. Further, cell managers reach greater T_{core} on account of their greater physical exertion.

Figure 6. Peak T_{core} plotted against starting USG for trainers and cell managers



A strong association (*R*=0.73) was found between instructor sweat rate and drink rate, with cell managers at the upper end and cell trainers at the lower end. Therefore, the greater an instructor sweats the more fluid is replaced by drinking.

Figure 7. Sweat rate plotted against drink rate for trainers and cell managers



Dermal and Biological Samples

Dermal patches

A total of 122 patch samples were collected over the 4 days of sampling (table 1). Of these, only 4 (3%) samples showed levels of one or more PAHs above the laboratory's limit of reporting (10ng/patch). As the primary purpose of this study was to evaluate the protective effectiveness of the merino undergarments/protective hoods, the decision was made to use the raw data without the limit of reporting applied (discussed further below). 50 of the 122 samples showed detectable levels of PAHs with this approach, and the most commonly detected PAH were phenanthrene, fluorene and pyrene.

Table 1: Dermal Patch PAH concentrations – sum of all PAHs detected on patch by region

Sample type	n (122)	n/% patches where PAH detected (>0ng/patch, n=50)	Ng/Patch Mean (SD) PAH (for those where detected)	Maximum (Ng)
Skin - under merino (knee/navel)	24	4 (17)	0.3 (0.83)	3
skin - no merino (knee/navel)	23	12 (52)	2 (4.5)	20
Merino surface (knee/Navel)	22	7 (32)	1 (2.3)	10
Skin - under protective hood (Neck)*	22	11(50)	3 (5.1)	21
Protective hood surface (Neck)	23	16 (70)	5 (4.9)	14
Dummy - under protective hood ('skin')	4	0 (0)	0 (0)	0
Dummy - protective hood surface	4	3 (75)	2 (1.2)	2
Skin - no merino - Navel only	11	6 (55)	2 (3.1)	11
Skin - no merino - Knee only	12	7 (58)	3 (5.6)	20
Safety officer (single neck patch on skin)	2	2 (100)	12 (6.0)	18

A smaller proportion of patches placed underneath the merino undergarments (on the skin) showed detectable levels of PAHs compared to those placed on the surface of the merinos and on the skin with no merino worn (17% vs. 32% and 52% respectively), and average PAH levels on these patches were also lower (mean for patches where any PAHs detected, 0.3ng/patch vs. 1.0 and 2.0).

A similar pattern was observed for patches placed under vs. on the surface of the protective hood, but the proportion of patches with detectable PAHs, and the levels of PAHs were generally higher (50% vs. 70%; mean PAH levels, 3 vs. 5ng/patch). PAH levels were also generally higher at this site (neck) compared to the other patch sites (knee/navel).

None of the control ('Dummy') patches placed under the protective hoods showed detectable levels of PAH, but 3 of the 4 patches placed on the surface of the protective hood did, with an average total PAH level of 2ng/patch. Finally, despite not being directly involved in the live fire scenario, PAHs were detected on both of the neck patches worn by safety officers, averaging 12ng/patch (6 and 18ng).

Urine samples

A total of 102 urine samples were collected over the 4 training days, including 24 pre-burn and 78 post-burn samples. A total of 4 planned post-burn samples were not able to be collected. None of the samples showed detectable levels of 3-hydroxyfluranthene (3-OH-FLU), so this compound was excluded from the data presented. Also, samples from one participant on day 2 showed an anomalously high ratio of 1-OH-NAP to 2-OH-NAP and were excluded, giving a total of 23 pre, and 74 post-burn samples.

Table 2 - Urinary OH-PAH levels in trainers – with and without merinos worn

		Avg. time sample collected	OH-NAPs			2-OH-FLU			OH-PHEs			1-PYR		
			# >MDL	Geometric Mean of samples >MDL (ng/ml)	Range	# >MDL	Geometric Mean of samples >MDL (ng/ml)	Range	# >MDL	Geometric Mean of samples >MDL (ng/ml)	Range	# >MDL	Geometric Mean of samples >MDL (ng/ml)	Range
With Merinos (n=11) - days 1&2														
Post-Burn	Pre-burn (n=11)	10:59 AM	11/11	**8.9**	1.2-29.9	7/11	**0.2**	0.2-0.4	0/11	-	-	1/11	**0.6**	ND-0.6
	1st Void (n=11)	1:57 PM	11/11	**15.2**	1.4-83.8	9/11	**0.5**	0.2-1.1	0/11	-	-	3/11	**0.2**	0.2-0.3
	2nd Void (n=11)	5:29 PM	11/11	**12.9**	4.5-49.0	10/11	**0.4**	0.2-1.0	2/11	**1.2**	1.1-1.2	5/11	**0.2**	0.2-0.4
	3rd Void (n=11)	6:45 PM	11/11	**12.4**	4.4-34.8	9/11	**0.4**	0.2-0.7	2/11	**0.7**	0.3-1.6	4/11	**0.5**	0.2-1.3
	4th Void (n=11)	1:10 AM	11/11	**7.4**	1.4-29.2	8/11	**0.3**	0.2-0.4	1/11	**0.5**	ND-0.5	1/11	**0.3**	ND-0.3
Without Merinos (n=12) - days 3&4														
Post-Burn	Pre-burn (n=12)	10:53 AM	12/12	**9.1**	2.2-45.9	9/12	**0.3**	0.2-0.5	1/12	**0.4**	ND-0.4	4/12	**0.2**	0.1-0.3
	1st Void (n=11)	1:03 PM	11/11	**11.6**	1.7-34.7	7/11	**0.5**	0.3-1.3	0/11	-	-	4/11	**0.2**	0.1-0.6
	2nd Void (n=9)	4:13 PM	9/9	**19.1**	11.2-42.7	7/9	**0.7**	0.5-1.7	3/9	**0.7**	0.4-1.1	6/9	**0.3**	0.2-0.9
	3rd Void (n=6)	7:04 PM	6/6	**16.9**	6.8-41.0	5/6	**0.6**	0.3-1.2	2/6	**0.9**	0.6-1.3	2/6	**0.4**	0.4-0.6
	4th Void (n=4)	9:17 PM	4/4	**13.2**	3.7-27.6	3/4	**0.4**	0.3-0.5	1/4	**0.5**	ND-0.5	1/4	**0.4**	ND-0.4

ND= not detected, or below MDL.

Although based on small numbers, urine analysis results showed an increase in OH-NAPs and 2-OH-FLU levels from pre-burn (void 0) to post-burn on training days where merinos were worn (1 and 2), generally peaking at voids 1-2 (~5 hours after starting live fire session) and then declining towards pre-burn levels with voids 3 and 4 (~7 and ~12 hours after starting training session). A similar trend was observed for days where merinos were not worn, but levels were generally higher than when merinos were worn.

Table 3 - Urinary OH-PAH levels in urine – by instructor role

		Avg. time sample collected	OH-NAPs			OH-FLUs			OH-PHEs			1-PYR		
			# >MDL	Geometric Mean of samples >MDL (ng/ml)	Range	# >MDL	Geometric Mean of samples >MDL (ng/ml)	Range	# >MDL	Geometric Mean of samples >MDL (ng/ml)	Range	# >MDL	Geometric Mean of samples >MDL (ng/ml)	Range
Cell managers (N=12)														
Post-Burn	Pre-burn (n=12)	10:56 AM	12/12	**6.9**	1.2-22.2	8/12	**0.2**	0.1-0.3	1/12	**0.4**	ND-0.4	1/12	**0.2**	ND-0.2
	1st Void (n=10)	1:16 PM	10/10	**10.3**	1.4-30.8	8/10	**0.4**	0.2-0.9	0/10	-	-	2/10	**0.2**	0.2-0.3
	2nd Void (n=10)	4:49 PM	10/10	**14.5**	4.5-49.0	8/10	**0.4**	0.2-1.0	3/10	**1.0**	0.8-1.2	5/10	**0.3**	0.2-0.4
	3rd Void (n=9)	7:35 PM	9/9	**11.6**	4.4-35.6	7/9	**0.4**	0.2-0.6	3/9	**0.9**	0.3-1.6	4/9	**0.6**	0.4-1.3
	4th Void (n=9)	12:53 PM	9/9	**7.3**	1.4-29.2	6/9	**0.3**	0.2-0.4	2/9	**0.5**	0.5-0.5	3/9	**0.4**	0.3-0.6
Trainers (n=11)														
Post-Burn	Pre-burn (n=11)	10:55 AM	11/11	**11.9**	4.2-45.9	8/11	**0.3**	0.2-0.5	0/11	-	-	4/11	**0.2**	0.1-0.6
	1st Void (n=11)	1:50 PM	11/11	**17.1**	4.7-83.8	8/11	**0.6**	0.3-1.3	0/11	-	-	5/11	**0.3**	0.1-0.6
	2nd Void (n=10)	4:59 PM	10/10	**16.4**	8.2-42.7	9/10	**0.6**	0.4-1.7	2/10	**0.7**	0.4-1.1	6/10	**0.3**	0.2-0.9
	3rd Void (n=8)	5:47 PM	8/8	**16.9**	8.1-41.0	7/8	**0.5**	0.3-1.2	1/8	**0.6**	ND-0.6	5/8	**0.4**	0.2-0.7
	4th Void (n=6)	1:30 AM	6/6	**11.1**	5.5-27.6	5/6	**0.4**	0.2-0.5	0/6	-	-	0/6	-	-

ND= not detected, or below MDL.

Urinary OH-PAH levels were marginally higher both pre-burn and post-burn in trainers. Trends (e.g. increases in levels from pre-burn, OH-NAPs highest) were consistent with findings for merino vs. non-merino days (table 2).

Discussion and Recommendations

Dermal and Biological Exposures to Carcinogens

The results of the exposure monitoring indicate that live fire training instructors are dermally exposed to PAHs, and this, most likely in combination with some exposure via alternative routes (i.e., inhalation and ingestion) is likely to explain the increase in body burden of PAHs observed (as elevated OH-PAH levels in urine) from pre-burn to post-burn. In addition, the differences in PAH concentrations found between patches worn on the skin underneath and on the surface of the merino undergarments (navel and knee sites, days 1 and 2) suggests that these garments are protective against dermal deposition of carcinogens. This is supported by the higher levels found on skin patches when no undergarments were worn (days 3 and 4).

Also, although levels were higher on average at the neck (compared to the knee/navel), the protective hoods also seem to be protective, and this was supported by the results of the control (dummy) samples; the higher levels observed on the skin at the neck compared to at the knee/navel sites highlights the importance of correct protective hood donning and doffing procedures (i.e., to prevent the transfer of contaminants from gloves/hands onto the neck). The relatively high levels found on the two neck patches worn by safety officers also suggests they are at risk of exposure and action should be taken to protect them accordingly.

As mentioned above, a high proportion (97%) of patch samples were below the laboratory's limit of reporting (LOR) of 10ng/patch for individual PAH compounds, and so the decision was made to use the raw concentration data without the LOR applied. The LOR is a minimum concentration defined by the laboratory based on the sensitivity of the method they have used to measure the concentration of a compound (i.e., PAH). If a result is below the limit of reporting, this doesn't mean the compound is not present, rather that the laboratory is not sufficiently confident in the reliability of results that fall below this limit. This is particularly relevant when assessing the significance of individual sample results, and/or comparing them to a regulatory limit (e.g., workplace exposure standards), but is of less concern when evaluating data at the group level for research purposes (e.g., when comparing average PAH levels when merinos worn vs. when not worn).

The reliability of the patch results reported here limits their use in decision making but provides an indication of the potential benefits of the merino undergarments and a basis for future research. Also, the fact that a high number of results were below the laboratory's limit of reporting (10ng/patch for individual PAH) suggests that both actual (on the skin) and potential (on the surface of the merino) dermal exposures during this specific live fire training week were relatively low and that the 'Level 2' outer garments are therefore somewhat effective at preventing dermal deposition of carcinogens.

The consistent trend of an increase in urinary OH-PAH levels from pre-burn to post-burn time points indicates, as expected, that trainers are being exposed to PAH during live fire training scenarios. General OH-PAH levels and trends in excretion characteristics (e.g., peak levels 4-6 hours after exposure commenced) were consistent with other comparable studies in live fire instructors (Banks et al. 2021, Fent et al. 2019) suggesting the results are valid. The highest OH-PAH levels were seen for OH-NAPs, followed by 2-OH-FLU and OH-PHEs (see appendix). This is again consistent with previous studies and suggests that more volatile PAH (i.e., Naphthalene) may penetrate protective clothing to a greater extent than others (Fent et al.

2019), something which should be considered when evaluating the effectiveness of interventions to control exposure.

In summary, The results of the exposure monitoring indicate that live fire training instructors are exposed to PAHs, and, despite some issues with the reliability of the patch data, that the merino undergarments are likely to be protective against skin exposure. They also suggest the protective hoods are protective but correct donning and doffing procedures are essential to prevent contamination of the neck area from contact with gloves/hands.

Recommendations

Although the sample size was relatively small, and the reliability of the patch data is limited, it is clear that live fire instructors are exposed to PAH as a result of participating in live fire scenarios. Introducing the merino undergarments resulted in lower PAH levels on patches, (both compared to on the surface of the merinos and when no undergarments were worn), suggesting they are an effective means of preventing dermal deposition of PAHs. This, in combination with the fact that they did not increase thermal stress and were generally well tolerated by trainers, suggests their use should be encouraged/facilitated for all live fire instructors (and most likely on-scene firefighters), or at the very least strongly supports further investigation of their effectiveness as a barrier to carcinogen exposure.

Protective hoods are inherently an essential element of the protective equipment required for any live fire scenario from a burn etc. prevention viewpoint; the findings of this study suggest they are also a barrier to dermal carcinogen exposure, but that correct donning and doffing procedures are essential. Evidence supports the overhead doffing technique as a more hygienic means of removing protective hoods – a recent study by Kesler et al. (2021) showed overhead doffing reduced levels of PAH contamination on the neck of firefighters taking part in live fire training by up to 89%. Researchers also evaluated differences in contamination levels between laundered and unlaundered hoods, and hoods constructed of different materials (e.g., knit vs blocking hoods) – all were shown to be protective (to varying degrees) but donning technique was the strongest predictor of contamination level.

In summary, the findings suggest that the merino undergarments are likely to be protective against skin exposure to carcinogens, and as they don't cause additional heat strain their use should be encouraged, or they should at least be trialled more extensively. Protective hoods also seem to be protective, but correct donning and doffing procedures are essential.

Future Research

The current study has provided limited evidence of the protective effectiveness of merino undergarments/protective hoods at preventing dermal carcinogen exposure, but issues with the reliability of the patch data limit their use for decision making purposes. Also, upon reflection, the sites chosen for placement of the patches, particularly the navel, were not ideal, as this resulted in the patches being covered by two layers of outerwear (top of overalls and jacket). An alternative, less occluded site (e.g., forearm, shoulder) may prove more

informative re. evaluating the protective effectiveness of the merinos. Furthermore, additional controlled experiments to evaluate their effectiveness (as were employed in this study for the protective hood) may prove informative. Finally, an evaluation of where entry of contaminants into the air space under the level 2 outer wear is greatest (e.g., wrist/ankle cuffs, collar) would provide a basis for designing interventions to reduce exposures by this route, e.g., a re-design/adjustment of cuffs and collars, additional seals, etc. to help prevent entry of contaminants. Other studies have employed fluorescent tracer techniques to evaluate this (Ormond et al., 2019), and this approach could also be used as an alternative means of evaluating the protective effectiveness of the merino undergarments/protective hoods.

In summary, further research would help to confirm the effectiveness of the merino undergarments at preventing skin exposure to carcinogens. An evaluation of where contaminants enter the level 2 outer garments, for example with fluorescent tracer techniques, would also provide a basis for developing other strategies to reduce skin exposures amongst instructors and firefighters alike.

References

Banks AP, Thai P, Engelsman M et al. (2021). Characterising the exposure of Australian firefighters to polycyclic aromatic hydrocarbons generated in simulated compartment fires. *Intl J Hyg Environ Health* 231:113637.

Cheuvront SN, Carter R, Montain SJ et al. (2004). Daily body mass variability and stability in active men undergoing exercise-heat stress. *Int J Sport Nutr Exerc Metab* 14(5)**:**532-540.

Cheuvront SN, Ely BR, Kenefick RW et al. (2010). Biological variation and diagnostic accuracy of dehydration assessment markers. *Am J Clin Nutr* 92(3)**:**565-573.

Fent KW, Toennis C, Sammons D et al. (2019). Firefighters' and instructors' absorption of PAHs and benzene during training exercises. *Int J Hyg Environ Health* 222(7): 991-1000.

Kesler RM, Mayer A, Fent KW et al. (2021). Effects of firefighting hood design, laundering and doffing on smoke protection, heat stress and wearability. *Ergonomics*, 64(6):755-767.

Kirk KM, Logan MB (2015). Firefighting instructors' exposures to polycyclic aromatic hydrocarbons during live fire training scenarios. *J Occup Environ Hyg* 12(4): 227-234.

Laitinen J, Mäkelä M, Mikkola J et al. (2010). Firefighting trainers' exposure to carcinogenic agents in smoke diving simulators. *Toxicol Lett* 192(1): 61-65.

Ormond, R., Kwon, C., & Mathews, M. (2019). Performance Evaluation of Newly Developed Smoke and Particulate Resistant Structural Turnout Ensemble. In *Homeland Security and Public Safety: Research, Applications and Standards*. ASTM International

Sawka MN, Burke LM, Eichner ER et al. (2007) American College of Sports Medicine Position Stand. Exercise and fluid replacement. *Med Sci Sports Exer* 39:377-390.

Seixas NS, Robins TG, Moulton LH (1988). The use of geometric and arithmetic mean exposures in occupational epidemiology. *Am J Indus Med* 14(4):465-477.

Wingfors H, Nyholm JR, Magnusson R et al. (2017). Impact of fire suit ensembles on firefighter PAH exposures as assessed by skin deposition and urinary biomarkers. *Ann Work Expo Health* 62(2): 221-231.

Appendix:

Target PAH - Dermal patch samples and limits of reporting

Target PAH	Limit of Reporting (ng/Patch)
Naphthalene	10
2-Methylnaphthalene	10
1-Methylnaphthalene	10
Biphenyl	10
2-Ethylnaphthalene (group of 2)	10
2,6-Dimethylnaphthalene (group of 2)	10
1,3-Dimethylnaphthalene (group of 3)	10
2,2-Dimethylbiphenyl	10
1,4-Dimethylnaphthalene (group of 3)	10
2-Methoxynaphthalene (group of 2)	10
Acenaphthylene	10
1,2-Dimethylnaphthalene	10
1,8-Dimethylnaphthalene	10
Acenaphthene	10
Fluorene	10
3,3-Dimethylbiphenyl	10
4,4-Dimethylbiphenyl	10
1-Methylfluorene	10
Phenanthrene	10
Anthracene	10
2-Methylanthracene	10
9-Methylanthracene	10
Fluoranthene	10
Pyrene	10
Benz(a)anthracene	10
Chrysene	10
Benzo(b+f+j+k)fluoranthene	10
Benzo(e)pyrene	10
Benzo(a)pyrene	10
Perylene	10
Indeno(1,2,3-cd)pyrene	10
Dibenz(a,h)anthracene	10
Benzo(g,h,i)perylene	10

Target OH-PAH in urine and respective method detection limits

Target OH-PAH	Acronym	Method detection limit (MDL, ng/mL)
1-hydroxynaphthalene	1-OH-NAP	1
2-hydroxynaphthalene	2-OH-NAP	0.05
2-hydroxyfluorene	2-OH-FLU	0.05
3-hydroxyfluorene	3-OH-FLU	0.1
1-hydroxyphenanthrene	1-OH-PHE	0.1
2/3-hydroxyphenanthrene	23-OH-PHE	0.05
4-hydroxyphenanthrene	4-OH-PHE	0.1
1-hydroxypyrene	1-OH-PYR	0.1