Title:

The Acute Effect of Training Fire Exercises on Fire Service Instructors

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ABSTRACT

Fire service instructors (FSI) regularly experience different types of fire exercises, however the strain experienced from these scenarios is not well understood. This study aims to identify the physiological and perceptual strain of Fire Service Instructors (FSI) to three training exercises: DEMO, ATTACK, COMPARTMENT, and the different roles performed: SETTER, INSTRUCTOR. The study also aims to assess the effect that different exercise patterns over a day (BOX, MULTI, COMBINATION) have on immunological responses. Sixteen FSI (age: 41±8yrs, body mass: 83.7±6.7kg, height: 177.0±6.7cm) were recruited, with 10 FSI completing the three exercises. Physiological and perceptual measures were collected prior to and immediately post each exercise. Venous blood samples were collected at the beginning and end of each day. One way analysis of variance (ANOVA) were conducted to assess differences in physiological variables between exercise types, independent samples t-tests were conducted between roles. Day changes in haemtological variables were assessed by paired sample t-tests and analysed by one way ANOVAs to identify differences between exercise patterns. The COMPARTMENT exercise resulted in a greater change in rectal temperature (ΔT_{re}) (0.49±0.28°C) than both the DEMO (0.23±0.19°C, $p=0.045$) and ATTACK (0.27±0.22°C, $p=0.016$). Within the COMPARTMENT exercise, the SETTER resulted in a greater ΔT_{re} and rating of perceived exertion than the INSTRUCTOR (0.67±0.29°C vs. 0.43±0.18°C, $p=0.027$ and 14±2 vs. 11±2, $p=0.001$, respectively). Following a day of fire exercises white blood cells (WBC), neutrophils, lymphocytes (LYMPH), monocytes (MONO), platelets (PLT), mean platelet volume (MPV), Interleukin (IL)-6, and cardiac troponin T (cTnT) all increased ($p<0.05$). Exercise patterns containing a COMPARTMENT exercise resulted in greater PLT, MPV, and IL-6. Total daily variation in ΔT_{re} was correlated with post exercise WBC, MONO, and

LYMPH. COMPARTMENT exercises produce the greatest physiological strain, with the SETTER role within this exercise causing the greatest $\Delta T_{re.}$ Although predominately physiological responses remain within safe limits. Exercise patterns that include a COMPARTMENT exercise also generate a greater inflammatory response.

INTRODUCTION

The physiological impact of a live fire has been well documented in firefighters (FF), with numerous detailed investigations conducted over the previous 30yrs.[1–6] It is widely established that performing physical exercise, being exposed to extreme temperatures, and carrying self-contained breathing apparatus (SCBA) result in both environmental and metabolic heat gain. Wearing heavy personal protective equipment (PPE), including the firefighting jacket, trousers, boots, fire hood, helmet, and gloves, also limits evaporative heat loss, therefore reducing an individual's ability to dissipate heat. Consequently, an uncompensable environment occurs, in which evaporative heat loss is less than that required to maintain a thermal steady state, causing the body to store heat.[7,8] Skin temperature, heart rate (HR), core temperature (T_c), and perceived effort subsequently increase. Ultimately this heat storage would result in heat stroke if an individual does not cease exercise and/or is not removed from the heat source.[5] During training activities a T_c upper safety limit of 39ºC is recommended. [9,10] However, there is a paucity in research into the response exhibited by Fire Service Instructors (FSI), with only Eglin et al. [11,12] and Watt et al.[13] having used FSI as participants. Whilst the environment experienced may be similar, FSI perform different tasks to FF.

FSI are responsible for the safety of FF, for instructing and training them, and also for setting the conditions in which the training occurs. Consequently, FSI tasks include setting fires, moving pallets or boarding, opening vents, positioning dummies or teaching FF. Instructing often entails resting in cooler parts of the building to observe the FF.[11] Following a training exercise FSI have been reported to have an increase in T_c of 0.4-1.0°C with a maximum HR of 121-138 b min^{-1} ,[11–13] in comparison to increases of 1.4-3.2°C in T_c and maximum HR of 134-194 b min^{-1}

recorded from FF.[2,14,15] This suggests that FSI may be working at a lower intensity of physical activity than FF, perhaps due to the type of occupational tasks being performed. Nevertheless, FSI experience fire conditions more frequently than FF, with FSI completing 13 ± 8 exercises a month compared to 1 ± 3 fires experienced by FF.[16]

The work conducted by FSI is also multi-faceted, with different exercises used to teach different scenarios to FF. In a standard training day the order in which these exercises occur can also vary between training centres. See Figure 1 for an overview of exercise types and orders. Some centres conduct two single box exercises in a day (BOX), or two multiple-compartment exercises in a day (MULTI), whilst others perform a combination of two boxes in the morning and a multi-compartment in the afternoon (COMBINATION). Box exercises are completed in single purpose built modified containers. These containers are designed with a rear area for fire setting, side ventilation hatches, and a front area that can be used to watch fire development or perform interior fire attack. There are two types of single box exercises: a demonstration where trainees learn about fire behavior (DEMO), and an exercise where trainees practice fire suppression (ATTACK). Single box exercises focus on training FF about fire behaviour and the best approaches to dealing with the situation.[17] A multi-compartment exercise, which takes place in a training unit consisting of multiple connected compartments, is designed to use the skills gained in the box exercises, with FF possibly unaware of the exact location of the fire and instruction may be given to find and recover a dummy (COMPARTMENT). During these three exercise types the training fires are produced by burning wooden boards or pallets. Eglin et al.[11] alludes to the differences between these exercises, although few single boxes were conducted and therefore no direct comparisons between exercise types were made. During each type of exercise there are two active roles that FSI may conduct: a condition setter who sets and controls the fire environment, which may involve moving pallets and operating side ventilation doors/hatches, consequently spending time close to the fire itself (SETTER), or an instructor who is responsible for following trainees through the exercise and teaching during live interior fire attack situations (INSTRUCTOR). It is currently unknown if these exercise types or roles result in different levels of physiological strain, or what impact exercise patterns may have.

Live fires experienced by FF have been noted to stimulate an inflammatory response, with increases in biomarkers of inflammation occurring, such as IL-6, platelet numbers and significant leukocytosis.[15,18] These biomarkers have also been suggested to be involved with an increased risk of cardiac events,[19,20] which has been reported as the leading cause of death amongst FF.[21] Markers of cardiac muscle damage, cardiac troponin T (cTnT) and troponin I (cTnI), that are used in the diagnosis of myocardial infarctions,[22] have previously been noted to increase in FF following training fire exercises.[23] Immune disturbances following physical activity have also been suggested as the possible mechanism for the overtraining response,[24,25] which has been proposed to be present in some FSI.[13,16] Watt et al.[13] gives the first assessment of FSI inflammatory responses, reporting increases in IL-6 and WBC counts in the six FSI involved in the study. However, this finding is yet to be repeated in a larger population size, and the impact that exercise patterns may have on inflammatory responses is unknown. Being able to plan courses to minimise the physiological strain and inflammatory response experienced by FSI could in the long term reduce the risk of cardiac events.

This study aims to identify the physiological and perceptual response of Fire Service Instructors (FSI) to three different training exercise and the different roles performed within each exercise. The study also aims to assess the effect that different exercise patterns over a day may have on immunological responses and measures of myocardial damage. It was hypothesised that: 1) there will be a significant difference in T_c responses to different exercise, 2) there will be a significant difference in T_c responses to roles, 3) a day of exercises will result in an increase in inflammatory and cardiac risk markers, and 4) there will be a significant difference in inflammatory markers between exercise patterns.

METHOD

Sixteen FSI (age: 41 ± 8 yrs, body mass: 83.7 ± 6.7 kg, height: 177.0 ± 6.7 cm) were recruited from three training centres: East Sussex Fire and Rescue Service, Surrey Fire and Rescue Service, and the UK Fire Service College. Fourteen FSI were male, two were female. Participants gave informed written consent and completed a medical questionnaire. The study was approved by the University of Brighton ethics committee.

Participants were requested to avoid caffeine and exhaustive exercise 12 hours before each testing day, and alcohol 24 hours before. Participant adherence was checked with a questionnaire completed at the beginning of each testing day.

Experimental Design

Testing occurred for FSI at their respective training centres. A medical room or portable cabin was used as a base field laboratory to attach instruments to participants and collect baseline measures. Participants completed training exercises as per their normal job, with exercises forming part of a taught course. Female participants were monitored during exercises when they were in the early follicular stage of their menstrual cycle as ascertained via a self-reported menstrual cycle questionnaire.[26]

At the beginning of the day, prior to the first exercise, hydration status was checked via a urine sample, with euhydration confirmed as a urine colour (U_{col}) of ≤3, osmolarity (U_{osm}) of $<700 mOsm.kgH_2O^{-1}$ (Pocket Pal-Osmo, Vitech Scientific Ltd, Horsham, West Sussex, UK), and urine specific gravity (U_{spg}) of <1.020 (Hand Refractometer, Atago Co., Tokyo, Japan).[27] Hydration status was also reassessed prior to their afternoon exercise. See Figure 1 for a schematic of the experimental monitoring.

Training Exercises and Days

Training exercises were assessed as individual exercises, with blood samples assessed over a day involving multiple fire exercises. There were 3 types of exercises: DEMO, ATTACK and COMPARTMENT. Within each exercise FSI performed one of two roles, a SETTER or an INSTRUCTOR. In total 19 fire exercises were assessed. There were 12 total days monitored, made up of 3 different exercise patterns: BOX, consisting of 2 single box fire exercises, a DEMO and an ATTACK; MULTI: 2 COMPARTMENT exercises; COMBINATION, 2 single box exercises, a DEMO and an ATTACK, followed by a COMPARTMENT in the afternoon. Within each exercise up to 5 participants were monitored, and some participants completed the same exercise or pattern on more than 1 occasion. Overall 74 sets of individual exercise data and 36 sets of day blood data were recorded. Table 1 details the number of days assessed with participant anthropometric data, whilst Table 2 provides participant details for exercises and roles. Instructors were at times responsible for the outside safety of an exercise and consequently did not all complete every type of exercise.

Physiological Measures

Nude body mass was recorded prior to and within 15 min after each exercise (Adam GFK 10 digital body scales, Milton Keynes, Buckinghamshire, UK) to calculate sweat rate. Due to the dangerous nature of their job, and the frequency of exercises completed as part of a course, FSI were allowed to consume water ad libitum during and after exercises. Participants were requested to record the volume of water consumed, which was later taken into account for sweat rate calculations, as per Equation 1.

Participants were fitted with a downloadable HR monitor (Polar RS800 and Polar Team^2 System, Kempele, Finland), and asked to insert a rectal probe for core temperature (T_{re}) measurement (449H, Henleys Medical, Welwyn Garden City, Hertfordshire, UK). Participants were instructed to pass the probe 10cm past the anal sphincter, and temperature was then displayed on logging monitors (4600 Rectal Thermometer, Measurement Specialties, Dayton, Ohio, USA). Participants were also fitted with iButtons,(DS 1922L Thermochron Data Logger, Measurement Systems Ltd., Newbury, Berkshire, UK) placed on the pectoral, triceps, quadriceps, and gastrocnemius, with data from each location used to calculate mean skin temperature (T_{skin}), as per Equation 2.[28] Data were recorded following a 10 min rest period in the base laboratory prior to PPE being worn. Fire exercises began 30-60 min post resting period, as time was needed by FSI to brief FF, don PPE, and set up. HR and T_{skin} was recorded continuously during the exercise, whilst T_{re} was measured immediately on exit. Peak and average HR and T_{skin} were established from the continuous data collection. Change (Δ) in $T_{re,}$ HR, and T_{skin} were also ascertained from pre to post (T_{re}) or pre to peak (HR, T_{skin}) values. Total day variation in ΔT_{re} was also calculated from the sum of the ΔT_{re} from the exercises experienced in the day.

Equation 1.

$$\text{Sweat rate (L.h}^{-1}\text{)} = \text{((Body mass pre (kg) – Body mass post (kg)) + fluid consumed (kg)) / Time (minutes)} * 60$$

Equation 2.

$$T_{skin}\ (^{0}C) = 0.3(T_{chest} + T_{upper\ arm}) + 0.2(T_{upper\ leg} + T_{lower\ leg})$$

Perceptual Measures

Rating of perceived exertion (RPE),[29] thermal sensation (TS),[30] and a heat illness symptoms index (HISI)[31] were asked during the rest period and immediately post each exercise. RPE was assessed on a scale from 6 “no exertion” to 20 “maximal exertion” with 1.0 integers. TS was measured on a scale from 0 “unbearably cold” to 8 “unbearably hot” with 0.5 integers. The HISI involved participants being asked to score a range of symptoms from 1 “no symptoms” to 10 “had to stop due to symptoms”, covering symptoms up to those experienced during heat stroke.

Venous Blood Collection

A venous blood sample (10mL) was taken from the anti-cubital fossa by a phlebotomist during the rest period at the beginning of the day and within 30 min of the last exercise of the day. Samples were collected into EDTA tubes. The delay in sampling post exercise was due to FSI ensuring the safety of FF and the removal of PPE. Samples were analysed for complete blood counts (CBC) by an automated haematology analyser (XT2000i, Sysmex, Milton Keynes, Buckinghamshire, UK), within 2 hrs of collection. Haematological variables recorded from the CBC included: white blood cell count (WBC), platelet count (PLT), mean platelet volume (MPV), neutrophil count (NEUT), lymphocyte count (LYMPH), monocyte count (MONO), eosinophil count (EO) and basophil count (BASO). Blood samples were subsequently centrifuged at 4,500 rpm for a period of 10 min at 4°C to separate plasma. Plasma was pipetted into 1.5ml microtubes and stored at -86ºC for later IL-6 and CR-P ELISA analysis (Duosets, R&D Systems, Minneapolis, Minnesota, USA). IL-6 intra assay coefficient of variation (CV) was 8.6% and inter assay CV was 11.1%. CR-P intra/inter assay CV were 5.8% and 9.1% respectively. Plasma was also analysed for cTnT using an electrochemiluminescence assay (Roche Modular E170, fifth generation, Basel, Switzerland), which had an upper reference limit based on the 99th percentile of 14ng.L^{-1}. Post day haematology variables were corrected for changes in plasma volume.[32]

Statistical Analysis

All physiological, perceptual, and haematological variables data were analysed using IBM SPSS Statistics version 22 (Armonk, New York, USA), reported as mean ± SD, with significance set at $p \leq 0.05$. Data were tested for normality using the Shapiro-Wilk test. Effect sizes are presented as partial eta squared (η_p^2) for analysis of variance (ANOVA) results and Cohen's d for comparison between two groups of data, with Cohen's d_s used for independent groups, and Cohen's d_z for repeated measures. Cohen's d was interpreted as small ($d = 0.2$), medium ($d = 0.5$) or large ($d = 0.8$).[33]

Exercise Analysis

Due to the nature of the courses run by FSI time of data collection could not be altered, consequently change in physiological variables (ΔT_{re}, ΔT_{skin}, and ΔHR) were analysed via one way repeated measures ANOVA, to control for baseline variations due to circadian rhythms. Sweat rate and average HR were also analysed by one way repeated measures ANOVA. Two way repeated measures ANOVA were conducted on all other dependent variables (RPE, TS, HISI) between pre and post measurements to identify if there is a significant main effect for time (PRE vs POST) and exercise (ATTACK, DEMO, COMPARTMENT), and a significant interaction between time and exercise. Sphericity was assessed via the Mauchly test. Bonferroni corrected follow up tests were conducted where significant interactions were identified; corrected p values of follow up tests are presented.

Assessment of differences in physiological variables (ΔT_{re}, ΔT_{skin}, ΔHR, average HR, and sweat rate) between roles (SETTER vs INSTRUCTOR) in each exercise were performed via an independent samples t-test. Perceptual variables (RPE, TS, and HISI) were analysed via a two way between measures ANOVA to identify if changes over time (PRE vs POST) were different between role type (SETTER vs INSTRUCTOR) within each exercise.

Day Analysis

Paired samples t-tests were conducted to establish if there was a difference between pre and post levels of haemtological variables to assess the effect a day of exercises had on FSI CBC, IL-6, C-RP, and cTnT. Mann Whitney U tests were used where data violated normality assumptions. These variables were also analysed using a one way between subjects ANOVA to identify if there was a difference in change of each blood marker for the exercise patterns (BOX, MULTI, or COMBINATION). If homogeneity of variance assumption was violated, Brown-Forsythe correction was applied. Data that violated normality assumptions was analysed by a Kruskal-Wallis test.

Pearson's or Spearman's correlation coefficients were calculated for blood variables and total day variation in ΔT_{re}. Correlation coefficients were interpreted as described by Cohen [33], with a weak relationship $r < 0.03$, a moderate relationship $0.3 \leq r < 0.5$, and a strong relationship $r > 0.5$.

RESULTS

Hydration status

Hydration status in the morning was: U_{col} 3 ± 2, U_{osm} 458 ± 266 $mOsm.kgH_2O^{-1}$, and U_{spg} 1.014 ± 0.008. In the afternoon U_{col} was 3 ± 2, U_{osm} 566 ± 298 $mOsm.kgH_2O^{-1}$, and U_{spg} 1.017 ± 0.010. There was a significant increase in osmolality ($p=0.020$) and specific gravity ($p=0.040$) values from the morning to the afternoon. In total 69% of FSI started their morning exercise euhydrated, compared to 44% of FSI who began the afternoon exercise euhydrated.

Exercises

A complete DEMO, ATTACK and COMPARTMENT exercise was performed by 10 participants (age: 44 ± 8 yrs, height: 163.4 ± 29.1 cm, body mass: 92.0 ± 35.0 kg). The mean duration of each exercise type was: DEMO 33.7 ± 7.0 min, ATTACK 38.5 ± 8.7 min, and COMPARTMENT 38.5 ± 10.1 min. Live fire temperatures ranged from 70°C at floor level to 700°C at ceiling height depending on position in the structure, as detected by temperature probes permanently installed in the fire training structures.

Physiological Response to Exercises

See Figure 2 for ΔT_{re}, ΔHR, average HR, and ΔT_{skin} from the 10 participants who completed all exercise types. One way ANOVA of these participants' responses revealed significant differences in ΔT_{re} between the exercises ($p=0.004$, $\eta_p^2=0.465$), with COMPARTMENT (0.49 ± 0.28°C) resulting in a greater ΔT_{re} than DEMO (0.23 ± 0.19°C) ($p=0.045$, dz=1.00) and ATTACK (0.27 ± 0.22°C ($p=0.016$, dz=1.22). Absolute T_{re} post exercise was 37.79 ± 0.16 for DEMO, 37.92 ± 0.30 for ATTACK, and 37.92 ± 0.35 for COMPARTMENT, with T_{re} only exceeding 38.5°C on two occasions in the COMPARTMENT exercise. ΔHR and average HR were both not different between exercises ($p=0.225$, $\eta_p^2=0.153$ and $p=0.833$, $\eta_p^2=0.020$, respectively). When assessed as a percentage of exercise time, ΔHR was also not different at any % of time between exercise types ($p=0.772$, $\eta_p^2=0.075$).

ΔT_{skin} was different between exercise types ($p=0.011$, $\eta_p^2=0.396$), with a greater ΔTskin occurring in DEMO (7.52 ± 1.60°C) compared to ATTACK (5.19 ± 1.70°C) ($p=0.030$, dz=1.08). There was no difference between COMPARTMENT (7.41 ± 2.12°C) and either DEMO ($p=1.00$)

or ATTACK ($p=0.156$). When assessed as a percentage of exercise time, ΔTskin was not different at any % of time between exercise types ($F(18,162)=1.469$, $p=0.107$, $\eta_p^2=0.140$). Sweat rate was not different between the exercise types ($p=0.762$, $\eta_p^2=0.116$).

Perceptual Response to Exercises

Two way repeated measures analysis of the 10 participants who completed all exercise types revealed RPE increased post exercises ($p<0.001$, $\eta_p^2=0.965$), however this increase was not different between exercise types ($p=0.354$, $\eta_p^2=0.109$). Change in RPE was 5 ± 3 in DEMO, 6 ± 2 in ATTACK, and 5 ± 2 in COMPARTMENT. TS followed a similar pattern, increasing post exercise ($p<0.001$, $\eta_p^2=0.848$), but with no difference in increase between the exercise types ($p=0.598$, $\eta_p^2=0.056$). Change in TS was 2 ± 1 in DEMO, 1.5 ± 1 in ATTACK and 1.5 ± 1 in COMPARTMENT. An increase of 1 is the difference from “neutral” to “warm”, and increase of 2 from “neutral” to “hot”. HISI also increased over time ($p=0.002$, $\eta_p^2=0.66$) and was not affected by exercise type ($p=0.501$, $\eta_p^2=0.74$). Increases in HISI were 10 ± 9 in DEMO, 7 ± 6 in ATTACK, and 10 ± 11 in COMPARTMENT.

Roles

Data collected from all 16 participants was analysed for assessment of differences between role types.

Physiological Response to Roles

There was no difference in ΔT_{re} between SETTERS and INSTRUCTORS for the DEMO ($p=0.875$) or ATTACK exercises ($p=0.864$). However, for the COMPARTMENT exercise

SETTERS exhibited a greater ΔT_{re} than INSTRUCTORS (0.67 ± 0.29°C vs. 0.43 ± 0.18°C, (p=0.027, d_s=0.99). ΔHR was similar between SETTERS and INSTRUCTORS in the DEMO (p=0.668), ATTACK (p=0.648), and COMPARTMENT (p=0.488). Average HR was also similar between the roles for all exercise types (DEMO: p=0.251; ATTACK: p=0.584; COMPARTMENT: p=0.751). Furthermore ΔT_{skin} and sweat rate were similar between roles in the DEMO (p=0.537, p=0.870), ATTACK (p=0.487, p=0.066), and COMPARTMENT (p=0.339, p=0.385). See Figure 3 for ΔT_{re}, ΔHR, average HR, and ΔT_{skin} for the two roles in each exercise type.

Perceptual Response to Roles

TS increased in each exercise (p<0.001), but this increase was not affected by FSI role in the DEMO (p=0.400, η_p^2=0.032), ATTACK (p=0.360, η_p^2=0.040), and COMPARTMENT (p=0.064, η_p^2=0.126). RPE increased in all exercises (p<0.001), but the increase was also not affected by FSI role in the DEMO (p=0.220, η_p^2=0.068) and ATTACK (p=0.536, η_p^2=0.019). Alternatively, the increase in RPE following the COMPARTMENT exercise was different between roles (p=0.001, η_p^2=0.328), with post RPE being greater in SETTERS (14 ± 2) than INSTRUCTORS (11 ± 2) (p=0.002, d_s=1.35). HISI increased in all exercises (p<0.001), but this increase was not affected by FSI role in the DEMO (p=0.958, η_p^2=0.000) and ATTACK (p=0.537, η_p^2=0.018). In the COMPARTMENT exercise ANOVA analysis suggests HISI was different between the roles over time (p=0.042, η_p^2=0.150), although follow up tests did not identify differences pre or post exercise (p=0.316 and p=0.173, respectively).

Days

Haematological data collected from all 16 participants was analysed for assessment of differences pre to post a day containing fire exercises, and the impact of exercise patterns on variables.

Haematological Response

At the end of a working day containing fire exercises, analysis of CBC (n=36) revealed a significant increase in WBC, PLT, MPV, NEUT, LYMPH, and MONO ($p<0.01$). IL-6, C-RP, and cTnT levels were not normally distributed, as determined by the Shapiro-Wilks method. A Wilcoxon signed rank test revealed an increase in IL-6 ($p<0.001$) and cTnT ($p<0.001$), however there was a decrease in C-RP ($p=0.048$). See table 3 for mean ± SD for all hematology markers data.

Haematological Response to Exercise Patterns

Differences between exercise patterns were only identified for ΔMPV ($p=0.024$), ΔPLT ($p=0.035$), and ΔIL-6 ($p=0.013$). ΔMPV was greater following the MULTI (1.88 ± 1.29 fL) compared to BOX (0.28 ± 1.59 fL), ($p=0.020$, $d_s=1.07$). MULTI also resulted in a greater ΔPLT (81 ± 52 $10^9.L^{-1}$) than BOX (43 ± 25 $10^9.L^{-1}$) ($p=0.020$, $d_s=1.03$). ΔIL6 was greater in the COMBINATION order (2.35 ± 1.07pg.mL^{-1}) in comparison to both MULTI (0.91 ± 0.70 pg.mL^{-1}, $p=0.011$, $d_s=1.63$) and BOX (0.84 ± 0.82 pg.mL^{-1}, $p=0.003$, $d_s=1.68$). See Figure 4 for differences in ΔWBC, ΔPLT, ΔMPV and ΔIL-6 between the exercise patterns.

Correlations

Total variation in ΔT_{re} across a day were significantly correlated with ΔWBC (r=0.437, p=0.010), ΔMONO (r=0.588, p<0.001), post WBC (r=0.542, p=0.001), post MONO (r=0.729, p<0.001), and post LYMPH (r=0.513, p=0.002). Total ΔT_{re} was not correlated with any other haematological marker.

DISCUSSION

This study aimed to assess the physiological, perceptual, and immunological consequences of current UK FSI working practices, with specific focus on the impact of different exercise types, different roles performed, and different daily exercise patterns. The COMPARTMENT exercise type resulted in a greater ΔT_{re} than DEMO or ATTACK. In addition, in the COMPARTMENT exercise the SETTER had a greater ΔT_{re} and RPE than the INSTRUCTOR. Markers of inflammation and cardiac muscle damage were increased following a day of fire exercises, with MULTI resulting in a greater ΔPLT and ΔMPV, and COMBINATION causing the greatest ΔIL6.

Exercise Physiological and Perceptual Responses

Only two previous studies have investigated the physiological and perceptual responses of instructors to training fire exercises. Eglin et al. [11] document the responses from FSI at the UK Fire Service College, noting increased T_{re} of 0.27 ± 0.02°C (n=2) and 0.70 ± 0.46°C (n=4) from DEMO and ATTACK exercises, respectively. When all exercise types were grouped together, a mean T_{re} of 38.5 ± 0.9°C was reported (n=32). The authors concluded that the T_{re} remained within reasonable limits, <41°C, but that some FSI did present with a T_{re} of concern ≥39°C.

Eglin et al. [11] also reported maximum heart rates of 138 ± 26 b min^{-1} and average HR of 109 ± 22b min^{-1} (n=34). Watt et al. [13] reported similar T_{re} responses of 38.06 ± 0.34°C and 38.08 ± 0.26°C post an exercise (n=6) and average HR of 101 ± 17 b min^{-1} and 97 ± 10 b min^{-1}. The findings of this study are in accordance with both Eglin et al.[11] and Watt et al. [13], with overall post T_{re} from all exercise types and participants remaining within safe limits (37.92 ± 0.31°C) (n=74), although on two occasions FSI did display post T_{re} of ≥39°C. Overall peak HR (147 ± 20 b min^{-1}) and average HR (117 ± 5 b min^{-1}) were also similar to the findings of Eglin et al.[11] and Watt et al.[13]

Due to the larger number of fire exercises monitored and the use of multiple fire training centres, this study is the first to be able to offer a statistical comparison of the different types of exercises conducted by FSI. The COMPARTMENT exercise resulted in a ΔT_{re} 0.26°C and 0.22°C greater than DEMO and ATTACK, respectively. It is currently unclear what the long term implications of repeatedly experiencing increased T_c are, however, Watt et al. (2016) suggest that it may result in an overtraining effect, with possible health implications such as an altered immune function. In addition, FSI exhibited no differences in RPE or TS, suggesting that they are unable to subjectively detect differences in physiological strain between exercise types. Consequently, it can be suggested that consideration of scheduling for COMPARTMENT exercises is required.

Exercise Roles

Within the COMPARTMENT exercise there were significant differences in ΔT_{re} and RPE between the roles performed by FSI. When working as an INSTRUCTOR, teaching and monitoring trainees, FSI had a lower ΔT_{re} and RPE than those working as a SETTER. Although SETTERS are predominately outside the structure, they still wear full PPE and SCBA whilst performing tasks such as carrying pallets and moving ventilation doors, which are often close to the fire. It is likely that the increased ΔT_{re} and subsequent rise in perceived effort, is caused by the proximity to the source of the fire, alongside the more physically demanding tasks. Horn et al. [34] have recently provided comprehensive analysis of FF job roles during realistic firefighting scenarios created in purpose built multiple room structures. The authors found an increased ΔT_c during the outside ventilation role (1.84 ± 0.49 °C) compared to inside roles (0.93 ± 0.27°C). Although the ventilation aspect and location of the roles are similar, it is important to note that the exact tasks studied differ between this study and that of Horn et al. [34] For instance, the focus on a realistic fire scenario, rather than training, combined with the more demanding tasks required of FF in comparison to FSI, likely resulted in a greater level of physical activity. These differences therefore explain the greater ΔT_c reported by Horn et al. [34] than documented in this study. From an applied position, the staffing of courses should be considered, as it is postulated that role rotation, to minimise frequent conductance of the SETTER role, may reduce the cumulative physiological strain experienced.

Day Haematological Responses

Following a working day involving fire exercises, FSI experienced an increase in WBC (+24.7%), NEUT (+51.1%), LYMPH (+30.3%), and MONO (+42.6%). This replicates the findings of Watt et al. (2016) who also reported increases of WBC (+19.0%) and NEUT (32.3% and 26.7%), although differences in LYMPH and MONO were not noted. Smith et al.[35] and Walker et al.[15] also reported the occurrence of leukocytosis immediately following search and rescue tasks experienced by FF, although Walker et al.[15] provided the heat stimulus via gas burners to 100 ± 5°C rather than live fire. Both studies reported increased WBC (+85% and +20%, respectively) and NEUT (+54% and +40%, respectively), with Smith et al.[35] also noting increased LYMPH (+141%) and MONO (+134%). The greater increases noted by Smith et al.[35] are likely the result of the live fire and fire suppression tasks which did not use a standardised work pace, providing a greater level of physiological strain.

Leukocytosis following physical activity and a hot environment is mediated by demargination of leukocytes from the vasculature, generated by sympathoadrenal activation increasing circulating catecholamine, which reduce the interaction between leukocytes and endothelial cells.[35–37] Repeated neutrophilia may deplete bone marrow neutrophil stores,[38] and consequently neutrophils present in circulation may be less mature and have a reduced phagocytic and oxidative burst activity, as they are forced to leave the bone marrow before they are fully developed.[39] This may result in a decrease in the ability of the innate immune system to combat infection post activity. It is unknown what the long term implications of repeated increases in leukocyte counts are, however Watt et al.[13] report increased resting WBC in FSI compared to a non-heat exposed control group. Increased resting differential leucocyte counts are also a risk factor and prognostic indicator of cardiovascular outcomes.[40]

PLT and MPV are also associated with risk of atherothrombosis and cardiovascular event, with MPV on average 0.92 fL greater in individuals who suffer an acute myocardial infarction.[20] Increased PLT (+25.6%) and MPV (+8.0%) were exhibited by FSI following a day of fire exercises in this study. Larger platelets are metabolically and enzymatically more active, with a greater prothombotic potential, consequently MPV is associated with platelet aggregation, synthesis of thromboxane (a hormone released from platelets that stimulates aggregation), and expression of adhesion molecules.[41]

It is well established that PLT increases following physical activity.[42] Live fire scenarios have also been demonstrated to increase PLT by 5-31%.[15,23,43,44] In addition, Smith et al.,[43,44] noted that platelet function, specifically aggregability, was enhanced, with a decrease in closure time when the blood was exposed to epinephrine and collagen (-14% and -20%, respectively). However, Smith et al.[43] detected no significant change in MPV (Pre: 9.60 ± 1.81 fL vs Post: 9.56 ± 1.97 fL). To the author's knowledge, there have been no other assessments of MPV following live fires to compare this study's findings to. Furthermore, there is not currently a clear consensus on the impact that physical activity has on MPV. Previously it has been reported that MPV increases (+18%) with a treadmill stress test in patients with ischemic heart disease, although this finding was not repeated in healthy individuals [45]. Wright-Beatty et al.[46] also reported no significant differences in MPV in FF following 4x15min cycling in 35°C heat, although there was a trend ($p=0.073$) for an increase post cycling. Alternatively, Lippi et al.[47] report a small (+3%) but significant ($p<0.001$) increase in MPV post a half marathon and Ahmadizad & El-Sayed [48] have noted increased MPV with acute resistance activity in healthy participants. It is proposed that the combination of activity intensity, duration and the aerobic fitness of individuals are responsible for MPV changes, and consequently some scenarios may not elicit a great enough stimuli to generate an increased MPV.[42] The multi-faceted cause of physiological strain in FSI may explain why increased MPV was noted, with the increased duration in comparison to Smith et al.[43] the possible cause of the difference in findings between studies.

Additionally, increased IL6 (+27.6%) was noted post a day of exercises in FSI, however a decrease in C-RP (-7%) was seen. IL-6 is a pleitropic acute-phase cytokine that is released from contracting muscles, monocytes and endothelial cells during exercise.[49,50] One of its many functions is to stimulate the release of CRP, an acute-phase plasma protein, from hepatocytes.[51] Increased levels of IL-6 and CRP in the blood indicate that an inflammatory response has occurred. Watt et al.[13] also noted a 33% increase in IL-6 in FSI, although baseline levels of IL-6 were greater than those found in this study (Pre: 7.4 ± 1.5 pg.mL^{-1}, Post: 9.9 ± 4.4 pg.mL^{-1} vs. Pre: 4.09 ± 3.67 pg.mL^{-1}, Post: 5.22 ± 4.20 pg.mL^{-1}, respectively). Watt et al.[13] also reported a 10% reduction in C-RP post fire exercise, with postulation that this may be due to increased C-RP turnover as a result of greater removal or breakdown. These findings were also repeated by Walker et al., [52] with increases in IL-6, but not C-RP post live fire. Overall, the increased IL-6, combined with the increase in other haematological variables previously discussed, indicates an FSI experience an inflammatory response to training fire exercises, which is in line with previous findings.

Repeated elevations of IL-6 could lead to chronic elevation, as noted by Watt et al.[13] Resting increased IL-6 is associated with progression of atherosclerosis in individuals with vascular risk factors,[53] and is also linked with an increased risk of myocardial infarction in healthy individuals.[19] In addition, it has previously been proposed that repeated acute stress with insufficient recovery time results in the development of systemic chronic inflammation, as noted by elevated resting cytokine levels, and consequently may be a cause of overtraining symptoms.[24,54] IL-6 has been suggested as one of the key cytokines that may be involved in the cytokine hypothesis of overtraining, as it can stimulate responses such as fatigue and sleep disturbances.[24,55]

Completing a day of live fire exercises also resulted in increased cTnT. These findings are similar to that of Hunter et al.[23] who reported increased cTnI from 1.4 ng.L^{-1} to 3.0 ng.L^{-1} following a 20min training fire exercise completed by 17 FF. Changes in cTnT and cTnI are often reported following prolonged exercise such as marathon running and have been positively correlated with exercise intensity.[56,57] A meta-analysis of cTnT responses to exercise revealed that running and football playing lasting ≥60min can result in a rise of +26 ng.L^{-1} (95% CI, 5.2-46.0).[58] Although increases in cTnT have been noted from 30 min onwards when continuously running.[59] Considering this it is surprising that, given the low level of physical activity and duration of exercise that FSI experience, increased cTnT is exhibited. This indicates that heat exposure, and the physiological responses it generates, may contribute to a rise in cTnT, even without a high level of exercise intensity. Whilst the levels of cTnT reported in this study remain within the normal reference range, it can be suggested that the elevated levels noted post exercises indicates that minor myocardial injury may have occurred. Further research is required to identify what the long term implications of this may be for FSI.

When comparing exercise patterns, MULTI resulted in a greater ΔPLT and ΔMPV than BOX, whilst COMBINATION caused a greater ΔIL6 than MULTI and BOX. These findings indicate that days containing a COMPARTMENT exercise may lead to an increased inflammatory response and could put FSI at an increased risk of cardiovascular events. However, cTnT was not different between patterns, signifying that exercise patterns may not affect the level of myocardial damage. Considering the ΔPLT, ΔMPV, ΔIL6 and T_{re} responses together, it is suggested that where possible organisation of courses should avoid repeated COMPARTMENT exercises across numerous days. Future research should investigate the long term implication of different exercise schedules.

Day variation in ΔT_{re} displayed a significant positive correlation with ΔWBC, ΔMONO and post LYMPH. This suggests that ΔT_{re} may influence the inflammatory response in FSI, and consequently by reducing the ΔT_{re} experienced across a day, FSI may be able to reduce both the strain and the inflammatory response that they experience. Minimising T_c elevations may be possible through appropriate exercise scheduling, maintenance of a euhydrated status, and implementation of pre and post cooling strategies.[3,5,60–65] However, other hematological markers measured were not associated with ΔT_{re}, indicating that it may not be the only driving factor behind the increased inflammatory response and cardiovascular risk. It is important to note that total ΔT_{re} does not reflect the time that FSI spent at a high T_{re}, which unfortunately is unknown due to the absence of continuous measurements. Time spent at a higher T_{re} could potentially provide a greater association to inflammatory changes in FSI, as it gives a better understanding of thermal load.

Given the increased risk of cardiovascular events amongst fire service personnel, and the elevated T_{re} and increased levels of inflammation and myocardial damage highlighted by this study, regular occupational health checks of FSI should be considered. Furthermore, frequent assessment of individuals’ responses to fire exercises would enable identification of individuals who may have a reduced heat tolerance, could be used to assess usefulness of interventions designed to reduce T_{re}, or be used to monitor responses in light of alterations made to exercises. This type of assessment of physiological and perceptual responses could also be conducted on different populations and types of exercises and exposures not included in this study. Whilst the exact equipment used in this research may not be available or desirable for use, alternative devices to measure T_c and HR are available that could be used by fire service personnel outside of scientific studies.

Limitations

The research design used in this study provided strong ecological validity to current UK FSI working practices, and consequently findings of an extremely applied nature. However, as a result of this, numerous extraneous variables were not able to be controlled by the researchers, such as duration of exercises, exercise workload, and time of exercise completion. These issues have been taken into account where possible during data analysis, such as by assessing the change in physiological variables to account for changes in circadian rhythms, and analysing continuous HR and T_{skin} data as the percentage of the individuals exercise time. Due to individual expertise of FSI, unfortunately all participants were not able to conduct all roles during the exercises, preventing a repeated measures analysis from occurring. In addition, data collection was limited to the exercises and exercise patterns currently being run by the training centres. Consequently, not all 16 participants were able to be included in the comparison of exercise types, and repeated measures analysis of exercise patterns was not possible, as different training centres conducted different patterns. Blood sampling immediately post each exercise type was also not possible, due to the logistics of sample analysis within a suitable time frame and distance of training centres from laboratories. Consequently, only the impact that exercise patterns has on hematological variables was assessed.

CONCLUSION

In conclusion, FSI experience increased physiological and perceptual strain following a training fire exercises. These responses are exacerbated in the COMPARTMENT exercise, and more so in the role of SETTER in comparison to INSTRUCTOR. FSI also experience an increased inflammatory response to a day of exercises, with increased ΔPLT, ΔMPV, and ΔIL6 possibly indicating an increased risk of a cardiovascular event. Correspondingly, the increased cTnT post a day of exercises indicates that FSI may experience a minor level of myocardial damage. In addition, days containing a COMPARTMENT exercise further increase some markers of cardiovascular risk. Total day variation in ΔT_{re} was correlated with markers of inflammation, namely ΔWBC, ΔMONO and post exercise LYMPH, and consequently it can be postulated that minimizing the rise in T_{re} could decrease this inflammatory response. It is suggested that appropriate training practice scheduling, giving consideration to the frequency of COMPARTMENT exercises and conductance of the SETTER role, may reduce the cumulative physiological strain, and subsequent inflammatory response, experienced by FSI.

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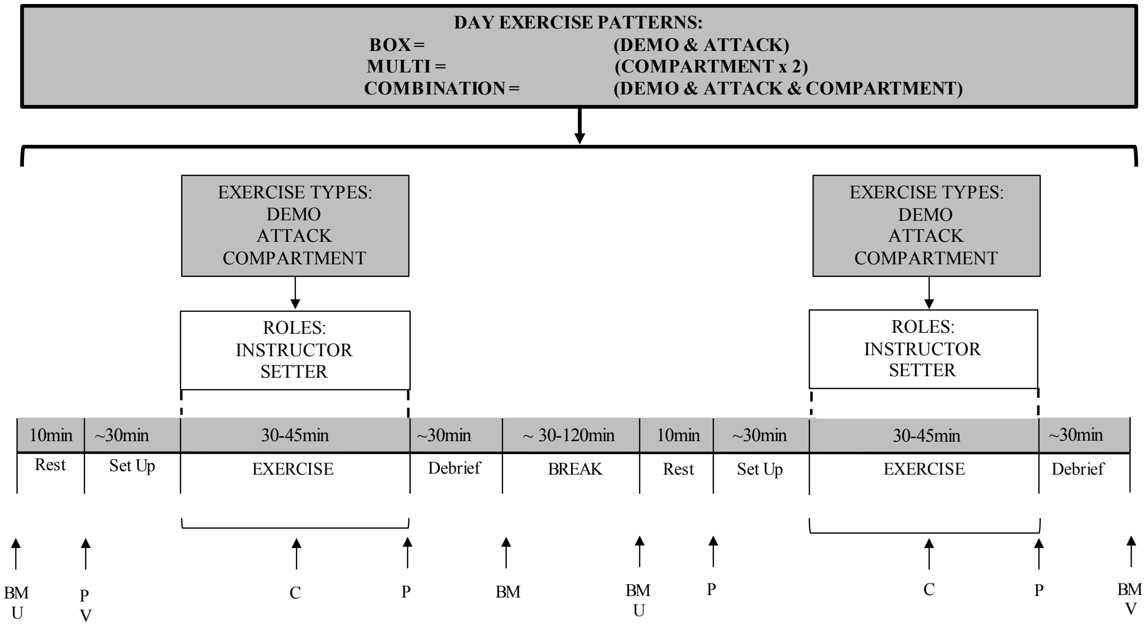

Figure 1. Schematic of experimental monitoring with data collection time points. The “Debrief” period included brief communication with students, any immediate fire ground tasks, and doffing of personal protective equipment. Abbreviations of measurement collections are: BM = nude body mass; U = urine hydration check; P = physiological and perceptual measurements of T_{re}, T_{skin}, HR, RPE, TS and HISI; V = venous blood sample; C = continuous HR and T_{skin}.

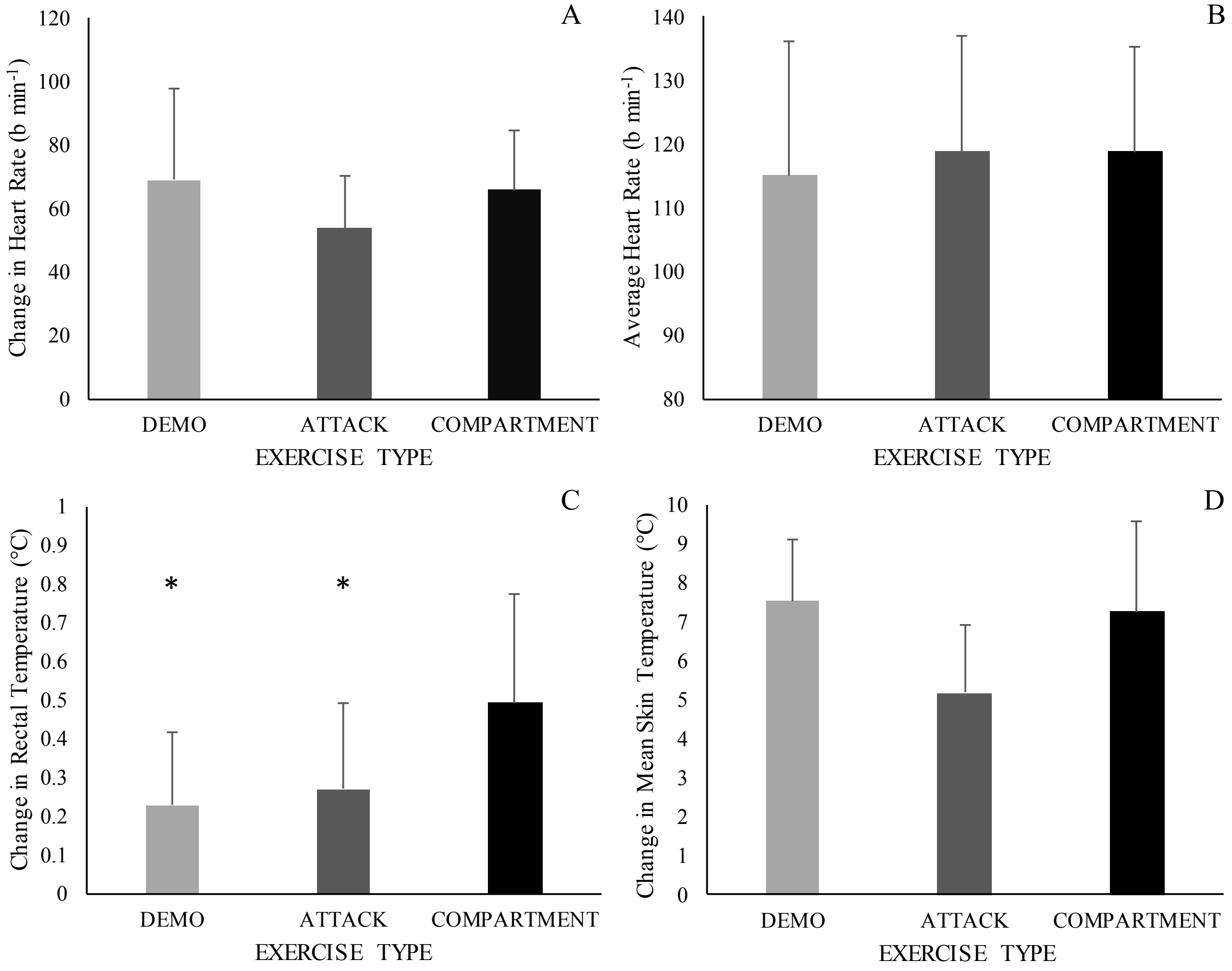

Figure 2. Physiological variables (mean ± SD) for each exercise from the 10 complete participants, graph A displays change in heart rate data, B average heart rate, C change in rectal temperature, and D change in mean skin temperature. * denotes a significant difference ($p<0.05$) from the COMPARTMENT exercise.

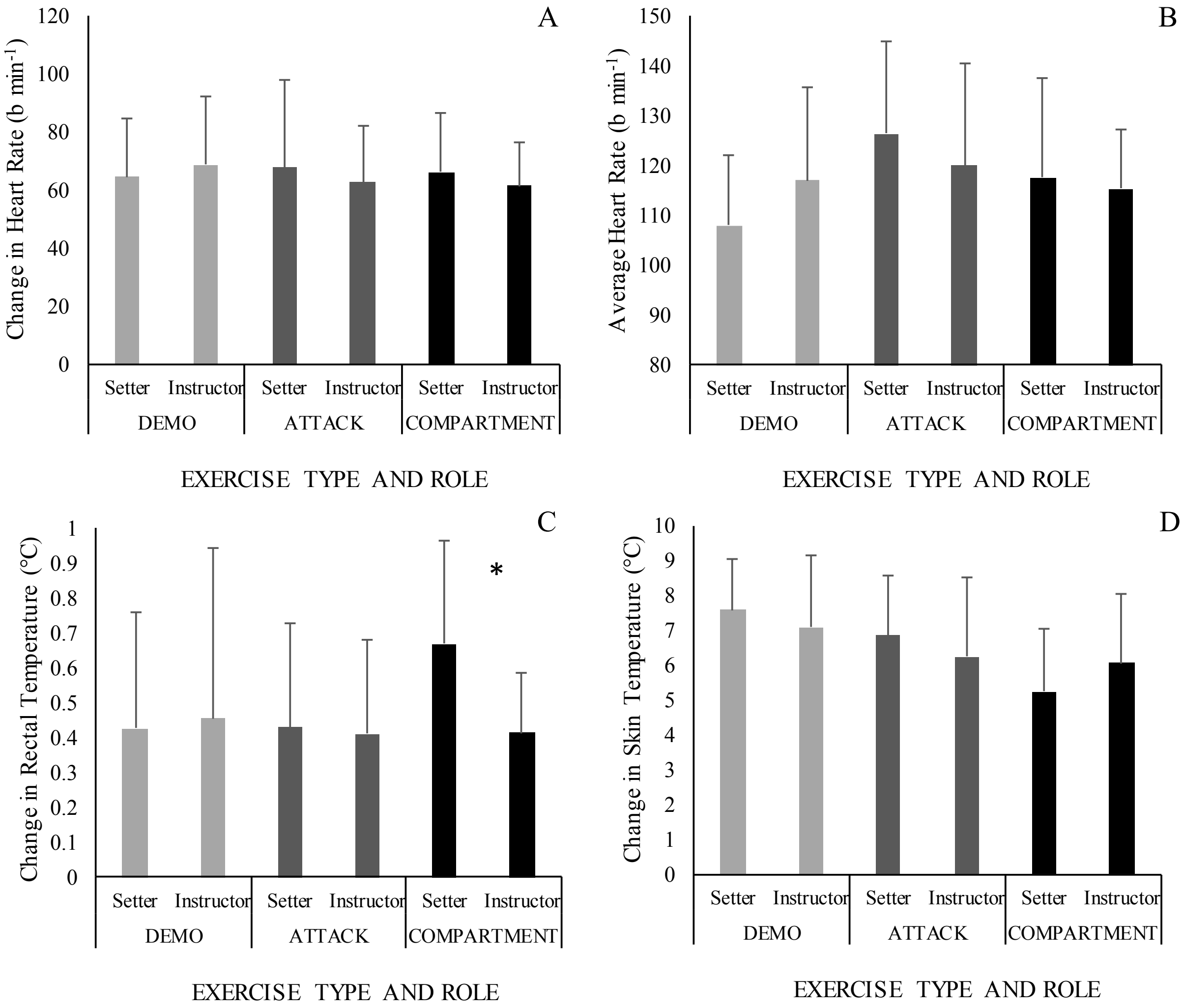

Figure 3. Physiological variables for both roles (SETTER and INSTRUCTOR) within each exercise type. Graph A displays change in heart rate data, B average heart rate, C change in rectal temperature, and D change in mean skin temperature. * denotes a significant difference between the roles.

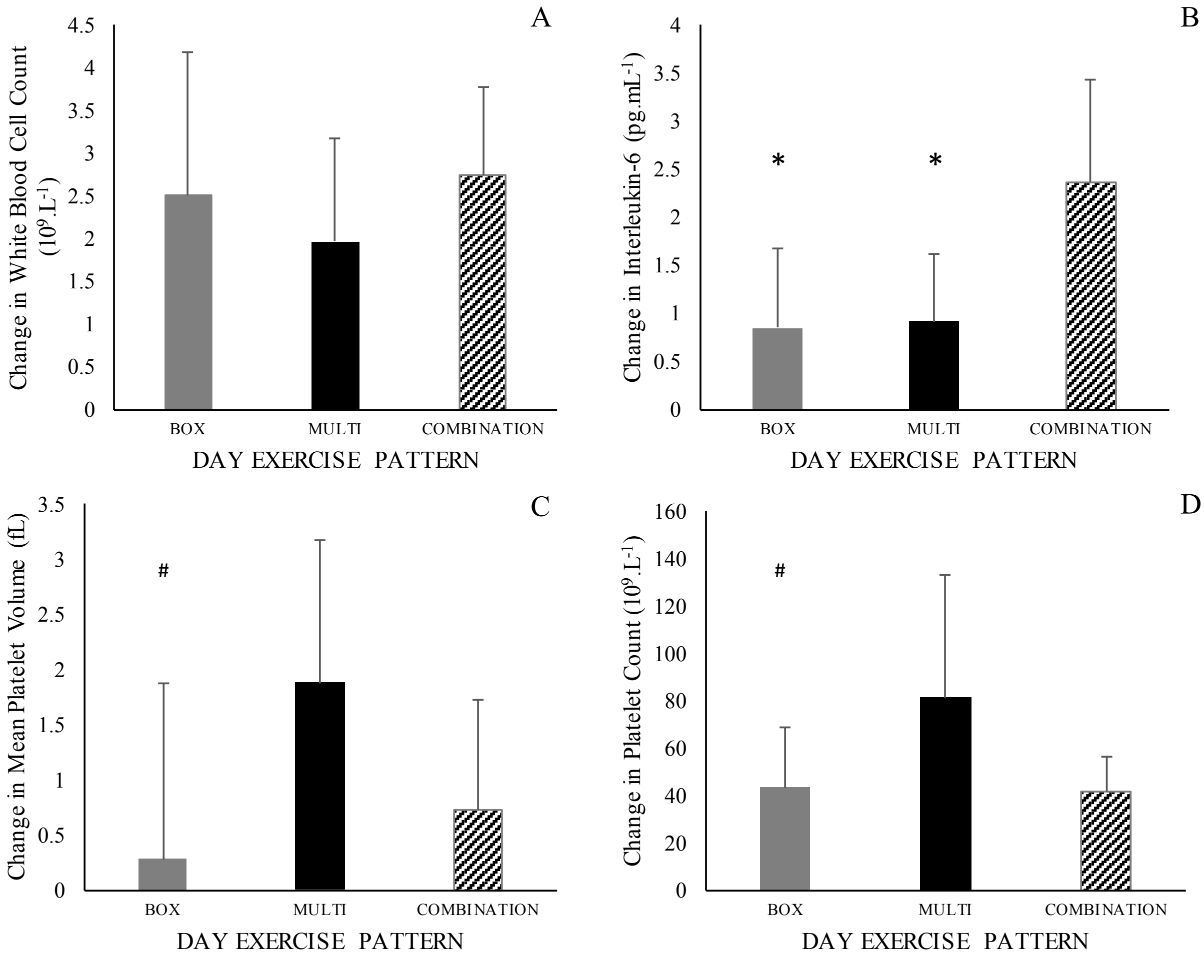

Figure 4. Haematological variables (mean ± SD) following different exercise patterns (BOX, MULTI, COMBINATION). Graph A displays change in white blood cell count, B change in interleukin-6, C change in mean platelet volume, and D change in platelet count. * denotes a significant difference from COMBINATION and $^{\#}$ denotes a significant difference from MULTI ($p<0.05$).

Table 1. Details the number of days collected with participant numbers and anthropometric data.

DAY **Exercise Patterns**	**Number of Days**	**Number of Participants**	**Participant Age (yrs)**	**Participant Height (cm)**	**Participant Body Mass (kg)**
BOX	18	10	42 ± 8	164.9 ± 29.9	94.5 ± 34.0
MULTI	10	6	41 ± 8	170.0 ± 9.2	80.6 ± 18.6
COMBINATION	8	6	46 ± 9	178.7 ± 4.0	84.3 ± 10.3

Table 2. Details the total number of exercises monitored and roles within each exercise collected, with participant numbers and anthropometric data.

EXERCISES						
Types	**Role**	**Number of Exercises**	**Number of Participants**	**Participant Age (yrs)**	**Participant Height (cm)**	**Participant Body Mass (kg)**
DEMO	SETTER	10	9	44 ± 9	177.2 ± 6.8	89.1 ± 12.0
	INSTRUCTOR	13	12	42 ± 8	175.8 ± 7.9	86.5 ± 13.4
	TOTAL	23	14	42 ± 7	175.4 ± 8.1	84.8 ± 14.1
ATTACK	SETTER	11	9	44 ± 8	174.7 ± 5.5	85.7 ± 13.8
	INSTRUCTOR	12	10	41 ± 8	175.4 ± 9.7	81.8 ± 14.9
	TOTAL	23	14	42 ± 7	175.4 ± 8.1	84.8 ± 14.1
COMPARTMENT	SETTER	10	4	45 ± 9	174.6 ± 8.5	80.9 ± 14.0
	INSTRUCTOR	18	11	43 ± 7	172.8 ± 7.8	78.0 ± 16.5
	TOTAL	28	12	44 ± 8	174.3 ± 8.2	82.4 ± 14.5

Table 3. CBC, IL-6, CRP and cTnT pre and post a FSI working day consisting of multiple fire exercises (n=36). * denotes a significant difference between pre and post a working day.

Haematological Variable	**Pre day (mean ± SD)**	**Post day (mean ± SD)**	**Effect size (d$_z$)**
WBC (10^9.L^{-1})	5.74 ± 1.01	8.15 ± 1.67*	1.69
PLT (10^9.L^{-1})	209 ± 43	262 ± 59*	1.45
MPV (fL)	10.33 ± 1.04	11.16 ± 2.15*	0.54
NEUT (10^9.L^{-1})	3.15 ± 0.91	4.76 ± 1.41*	1.25
LYMPH (10^9.L^{-1})	1.78 ± 0.44	2.32 ± 0.57*	1.13
MONO (10^9.L^{-1})	0.61 ± 0.18	0.87 ± 0.30*	1.05
EO (10^9.L^{-1})	0.15 ± 0.10	0.15 ± 0.10	0.10
BASO (10^9.L^{-1})	0.08 ± 0.19	0.05 ± 0.04	0.19
IL-6 (pg.mL^{-1})	4.09 ± 3.67	5.22 ± 4.20*	1.14
CRP (mg.L^{-1})	1.46 ± 1.42	1.36 ± 1.34*	0.35
cTnT (ng.L^{-1})	3.99 ± 1.38	5.44 ± 1.94*	1.08