



Physiological and perceptual responses while wearing stab-resistant body armor in hot and humid environment

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ABSTRACT

The aim of this study was to investigate the physiological and perceptual responses of the human body wearing stab-resistant body armor (SRBA) in a hot and humid environment. The responses of five healthy male volunteers wearing SRBA were compared with those under a Control condition (wearing T-shirt) in a hot and humid environment (38 °C and relative humidity of 60%). The participants walked on a treadmill at a speed of 6 km/h for 60 min and this was followed by 60 min of recovery. The physiological responses (core temperature, skin temperature, heart rate, oxygen consumption) and perceptual parameters (thermal sensation, thermal comfort, rate of perceived exertion (RPE), and restriction to movement) were recorded throughout the tests. The results showed that the use of SRBA resulted in higher values of core temperature, mean skin temperature, heart rate, and oxygen consumption during exercise, and a significant difference ($p < 0.05$) between the SRBA and Control trials in terms of oxygen consumption was observed. The subjects wearing SRBA exhibited higher RPE and restriction to movement during exercise when compared with those in the Control condition, and a significant difference ($p < 0.05$) between the two trials in terms of restriction to movement was observed. Moreover, no significant differences ($p > 0.05$) in terms of thermal sensation and thermal comfort were observed between the SRBA and Control trials. It was concluded that the use of SRBA imposed high thermoregulatory and cardiovascular strain, reduced perceived exertion, and restricted movement during exercise in the hot and humid environment, whereas its effect on thermal sensation and thermal comfort was negligible when compared with those in the Control condition.

1. Introduction

Stab-resistant body armor (SRBA) is commonly used by the police, military personnel, and first responders for protection against ballistic trauma, knife, and other tools (Pyke et al., 2015). Wearers often perform physically demanding movements, and the weight of SRBA has been shown to increase the metabolic rate (Ricciardi et al., 2008). However, the SRBA provides a barrier between the skin and its thermal environment and remarkably reduces heat loss from the human body, especially in hot environments where sweat evaporation is seriously impaired by the impermeable material (Ryan et al., 2015; Santee et al., 2015; Xu et al., 2013). Hence, the combined effect of these environmental, clothing, and human factors may result in heat storage in the human body and further increase the skin temperature, core temperature, heart rate, and oxygen consumption, which may cause serious thermoregulatory and cardiovascular issues and even lead to organ failure and

potentially death (Lucas et al., 2014; Maley et al., 2017).

In Previous studies (Cadarette et al., 2001; Cadarette et al., 2007; Dempsey et al., 2013, 2014; Larsen et al., 2012; Potter et al., 2015a; Potter et al., 2015b; Potter et al., 2013; Santee et al., 2015), the effects of body armor on physiological responses under different environmental conditions, clothing, and working intensities were investigated. Cadarette et al. (2001) evaluated heat strain imposed by six configurations of a modular body armor design. Cadarette et al. (2007) investigated wearing body armor with reflective thermal inserts to reduce the heat strain during exercise-heat stress with a radiant load. Dempsey et al. (2013) observed that participants wearing body armor significantly increased oxygen consumption, heart rate, and respiratory exchange ratio during high and moderate-intensity exercise. Larsen et al. (2012) evaluated the impact of body armor during simulated repetitive military work of intermittently high intensity, demonstrating that the use of body armor resulted in significantly higher core temperature but no change in heart

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rate. Potter et al. (2013, 2015a, 2015b) measured biophysical characteristics of body armor and predicted core temperature while wearing body armor under different environmental conditions. Moreover, maximum work times for various body armor ensembles under different environments (e.g., desert and jungle) were calculated based on the simulated core temperature. Generally, the subjects wearing body armor took treadmill tests in both climate chambers and field studies, and their typical physical responses, such as core temperature, skin temperature, heart rate, and metabolic rate, were measured throughout the tests.

Some studies determined the effect of SRBA on mobility (Dempsey et al., 2013), military task performance (Larsen et al., 2012), and landing forces (Dempsey et al., 2014). Dempsey et al. (2014) determined the impact of additional load and intense exercise on jumping performance and peak vertical ground reaction force when landing, indicating that carrying additional load greatly reduced jump height and increased ground reaction force when landing. It remains a challenge to develop high-performance body armor to provide both resistance protection and perceptual comfort. To date, few studies have evaluated perceptual responses to the use of SRBA in hot and humid environments. In fact, the lack of understanding of the wearer's perception and demand may result in improper or no use of protective clothing (Akbar-Khanzadeh et al., 1995; Huck, 1988). Therefore, it is critical to evaluate the influence of SRBA on the wearer's physiological responses and perceptual responses in hot environments to improve thermal comfort, manage heat stress, and enhance work efficiency.

In this study, the physiological and perceptual responses were analyzed through human trials. Firstly, five male volunteers wearing either SRBA or T-shirt (Control) walked on a treadmill at a speed of 6 km/h in a hot and humid environment, and this was followed by recovery for 60 min. Secondly, the physiological responses were measured throughout the trials and the perceptual responses were obtained through the surveys. Finally, the effects of the use of SRBA on the physiological and perceptual responses were analyzed. The study can provide fundamental knowledge for use in heat stress management, determination of maximum working time, and design of high-performance SRBA to further improve its benefits to the wearers.

2. Methods

2.1. Subjects

Five healthy male volunteers were recruited to participate in the trials, the physical characteristics (Mean \pm standard deviation (SD)) of these subjects are shown in Table 1. The current study was approved by the Beijing Institute of Technology Human Research Ethics Committee. Prior to the trials, all the subjects gave written informed consent showing the purpose, procedures, benefits, and potential risks of this study. The subjects were required to be physically active with no history of neurological deficits, hypertension, or cardiovascular disease. Moreover, the subjects were asked to refrain from the use of tobacco, alcohol, and caffeine as well as strenuous exercise for 24 h prior to the tests. The body surface was calculated using the Dubois equation (DuBois, 1916).

2.2. Stab-resistant body armor

The SRBA (FCF-F-ZT03, Hunan Zhongtai Special Equipment Co., Ltd, China) has an area of 0.3 m² and weight of 3.5 kg and is commonly used by the Chinese police. It is detachable and sleeveless and mainly applied to cover the torso of the human body including chest, stomach, shoulder, and back. It is composed of ultra-high molecular weight polyethylene

Table 1
Physical characteristics of the subjects (Mean \pm SD).

Age (year)	Height (cm)	Weight (kg)	Body surface (m ²)
22.2 \pm 1.3	174.8 \pm 3.4	66.8 \pm 1.6	1.8 \pm 0.1

fiber. The total thermal and evaporative resistances of the SRBA are 0.23 m² K/W and 220 m² Pa/W, respectively, as measured using a 20-zone 'Newton' sweating thermal manikin (Thermetrics, Seattle, USA) in accordance with the testing standards (ASTM F1291-16; 2016; ASTM F2370-16; 2016).

2.3. Test protocol

An environmental condition of 38 °C and relative humidity of 60% was selected to represent a hot and humid summer day. The hot and humid environment was set in a climate chamber where the temperature (10–45 °C \pm 1.0 °C) and relative humidity (40–98% \pm 5%) can be independently controlled. The air velocity was controlled at 0.4 m/s \pm 0.1 m/s during the tests. Each subject participated in two trials (SRBA and Control) in a randomized order and walked on a treadmill at a speed of 6.0 km/h. Moreover, the treadmill was set at a grade of 0%. Prior to the tests, the subjects were asked to rest for 30 min while seated in the chamber. The tests comprised two experimental sessions for a total duration of 120 min: session 1, walking at 6.0 km/h for 60 min; session 2, sitting for 60 min. In the Control condition, the participants wore shorts, underwear, socks, sports shoes, and T-shirts during the test. In the SRBA condition, the armor was worn over the T-shirt, as displayed in Fig. 1.

The core temperature (Tre) was measured using an ingestible telemetric pill (CorTemp[®], HQInc, Palmetto, USA), which was swallowed by each participant 2 h prior to the test. The skin temperature (YSI 427, Measurement Specialties Inc., Hampton, USA) was measured continuously at the segments of forehead, scapula, chest, upper arm, lower arm, hand, thigh, and calf. The mean skin temperature was calculated from the local skin temperature (ISO9986, 2004) with weighting coefficients of 0.07, 0.175, 0.175, 0.07, 0.07, 0.05, 0.19, and 0.2 for the forehead, scapula, chest, upper arm, lower arm, hand, thigh, and calf, respectively. The heart rate (Polar Electro Oy, Kempele, Finland), and oxygen



Fig. 1. Human trials in the climate chamber.

consumption (Moxus, AEI Technologies, Pittsburgh, USA) were recorded throughout the trials.

Assessments of perceptual responses (thermal sensation, thermal comfort, rate of perceived exertion (RPE), and restriction to movement) were assessed through surveys every 10 min during the tests. Furthermore, the thermal sensation of the human body was measured on a nine-point scale (Zhang et al., 2010b): -4 = *very cold*; -3 = *cold*; -2 = *cool*; -1 = *slightly cool*; 0 = *neutral*; 1 = *slightly warm*; 2 = *warm*; 3 = *hot*; and 4 = *very hot*. The thermal comfort of the human body was also obtained using a questionnaire (Zhang et al., 2010a): -4 = *very uncomfortable*; -2 = *uncomfortable*; 0 = *just comfortable*; 2 = *comfortable*; and 4 = *very comfortable*. The RPE was recorded on a 15-point scale (Borg, 1982): where 6&7 = *very, very light*; 8&9 = *very light*, 10&11 = *fairly light*; 12&13 = *somewhat hard*; 14&15 = *hard*; 16&17 = *very hard*; and 18&19&20 = *very, very hard*. The restriction to movement was recorded on a five-point scale (Wen et al., 2015) during the pre-test, test, and post-test stages: 0 = *no restriction*; 1 = *slightly restricted*; 2 = *restricted*; 3 = *very restricted*; and 4 = *extremely restricted*.

2.4. Data analysis

The core temperature, mean skin temperature, heart rate, oxygen consumption, thermal sensation, thermal comfort, RPE, and restriction to movement were analyzed via one-way ANOVA using SPSS 24.0 (IBM Corp., Armonk, USA). A *p*-value of less than 0.05 indicated statistical significance, and all the data were shown in the form of mean \pm SD. Furthermore, paired *t*-tests were performed if significant differences were observed.

3. Results

3.1. Physiological responses

In Fig. 2, the core temperature is displayed as ΔT_c to normalize slight variations in the initial core temperature (Selkirk et al., 2004). Although no significant difference ($p > 0.05$) was observed among these trials for these dependent measurements, the overall rate of core temperature increase in the SRBA trial was greater than that in the Control trial. The core temperature continuously increased in both the trials during the walking session, and the rates of increase in the SRBA and Control trials were 2.5 °C/h and 2.1 °C/h, respectively. The core temperature gradually decreased in both the trials as expected during the period of rest, but the ΔT_c in the SRBA trial remained higher than that in the Control trial. Moreover, the core temperature decreased by 1.1 °C in the SRBA trial and by 0.9 °C in the Control trial.

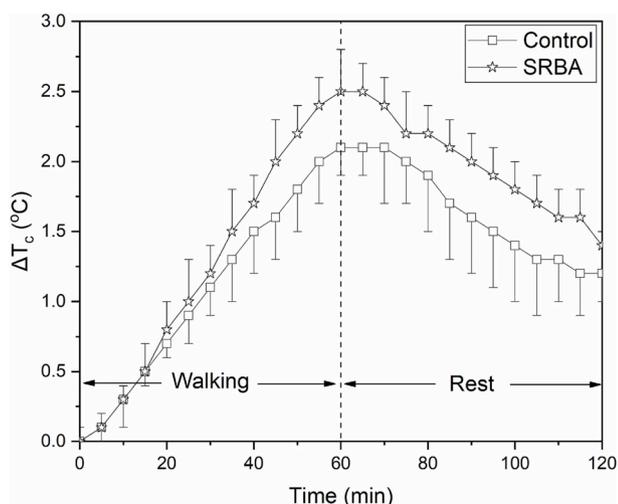


Fig. 2. Core temperature in SRBA and Control conditions.

The mean skin temperature rapidly increased during the walking session and thereafter began to decrease until the end of the tests, as shown in Fig. 3. The peak values of mean skin temperature ($t = 60$ th min) in the SRBA and Control trials were 39.7 °C and 39.0 °C, respectively. The rate of mean skin temperature increase in the two trials was almost identical during the walking session, and the values were 4.1 °C/h and 4.0 °C/h in the SRBA and Control trials, respectively. However, the rate of mean skin temperature decrease in the SRBA trial was 50% greater than that in the Control trial during the recovery period, and the values were 1.5 °C/h and 1.0 °C/h, respectively. The mean skin temperatures at the end of the trial were greater than the initial values by 2.6 °C and 3.0 °C in SRBA and Control trials, respectively. Moreover, the mean skin temperatures remained at approximately 38.0–38.2 °C even after passive rest for 1 h.

The heart rate increased remarkably during the walking session and thereafter declined throughout the period of rest in both the trials, as shown in Fig. 4. Although the heart rates during the walking and rest sessions were higher in the SRBA trial than in the Control condition, no significant difference ($p > 0.05$) was noted. The heart rate increased to 159–169 bpm; however, no significant difference ($p > 0.05$) was observed between the two trials. The heart rate increased rapidly by 36 beats in the SRBA trial and by 39 beats in the Control trial in the first 10 min and exhibited relatively stable increment thereafter. During the rest session, the heart rate decreased rapidly from 169 bpm to 116 bpm in the SRBA trial and from 159 bpm to 111 bpm in the Control trial. Moreover, the heart rate at the end of testing remained higher than its initial value by 14.9% and 18.1% in the SRBA and Control trials, respectively.

Considerable increments in oxygen consumption were observed in both the SRBA and Control trials during the walking session, especially in the first 5 min, as depicted in Fig. 5. The oxygen consumption values at 5th min were 1.9 times and 2.3 times higher than its initial value ($t = 0$ th min) in the SRBA and Control trials, respectively. Additionally, a significant difference ($p < 0.05$) between the two trial conditions in terms of oxygen consumption was observed during the walking session. The peak values of oxygen consumption in the SRBA and Control trials were 27.7 mL/(kg·min) and 20.2 mL/(kg·min), respectively. The oxygen consumption values in the SRBA and Control trials at the 65th min were 72.2% and 62.7% lower than those at the 60th min, respectively. Moreover, the oxygen consumption values at the 120th min were lower than the initial values in both the SRBA and Control conditions, indicating 1 h of rest was sufficient for the subjects to recover in terms of oxygen consumption. The oxygen consumption reached steady state after 10 min of rest in both the SRBA and Control conditions, and the values were in the range 5–10 mL/(kg·min).

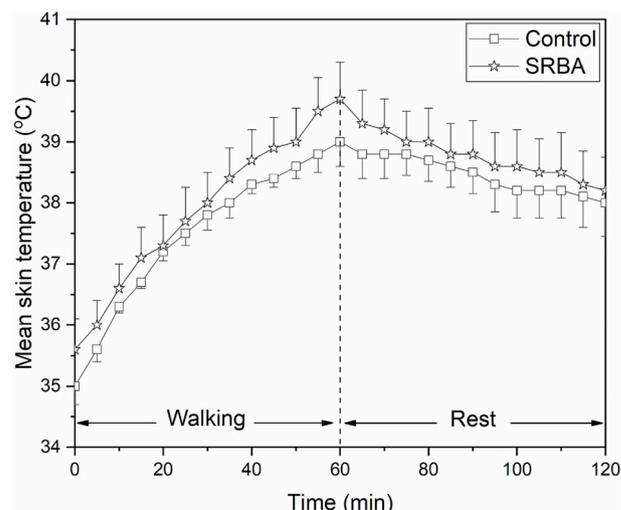


Fig. 3. Mean skin temperature in SRBA and Control conditions.

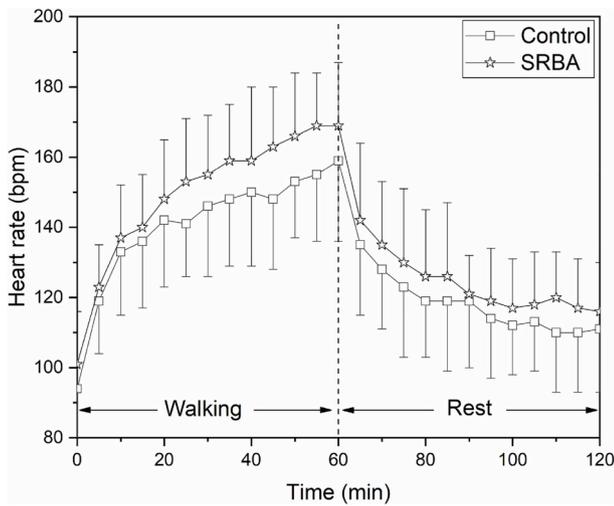


Fig. 4. Heart rate in SRBA and Control conditions.

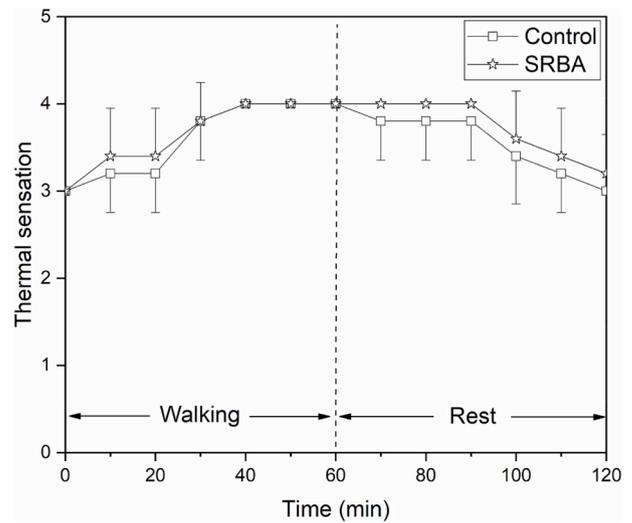


Fig. 6. Thermal sensation in SRBA and Control conditions.

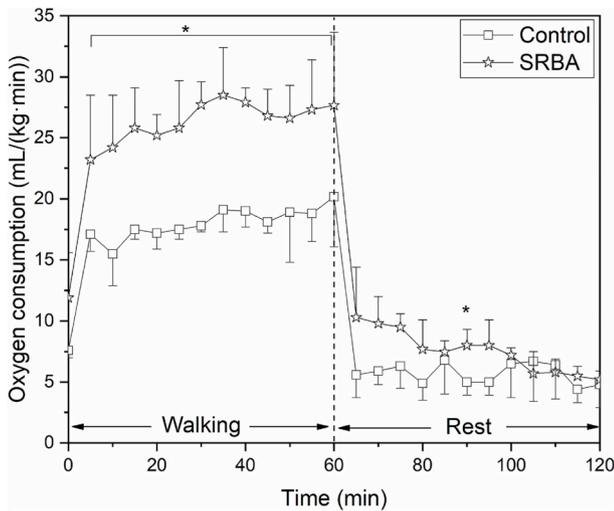


Fig. 5. Oxygen consumption in SRBA and Control conditions (*, $p < 0.05$).

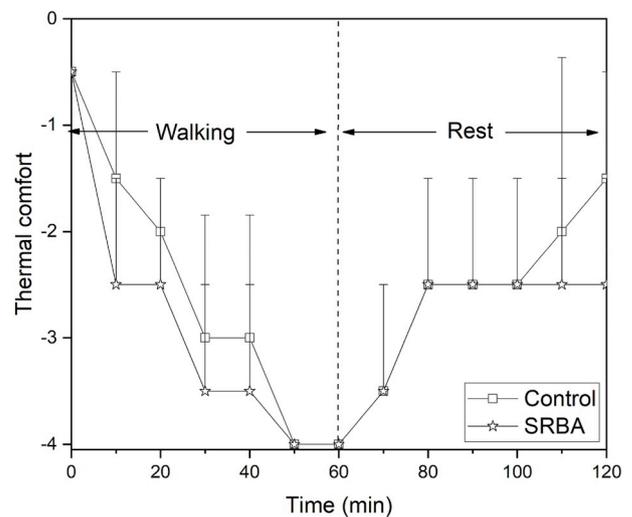


Fig. 7. Thermal comfort in SRBA and Control conditions.

3.2. Perceptual responses

The thermal sensation increased during the walking session and declined during recovery in both the SRBA and Control trials, as shown in Fig. 6. No significant difference ($p < 0.05$) between the SRBA and Control trials was observed in terms of thermal sensation during both the walking and rest sessions. The thermal sensation values in the SRBA condition were in the range 3.0–4.0 during the walking session and reached 3.2 at the end of the trials, indicating that the subjects felt between ‘hot’ and ‘very hot’ during the walking and rest sessions. Similarly, the thermal sensation values in the Control trial were in the range 3.0–4.0 during the walking session and returned to 3.0 at the end of the test.

The thermal comfort in the SRBA and Control trials decreased during the walking session and increased during the rest session, as displayed in Fig. 7. There was no significant ($p > 0.05$) difference in terms of thermal comfort between the SRBA and Control conditions. The subjects felt ‘uncomfortable’ in both the SRBA and Control conditions at the start of the test and thereafter experienced a fast decrement in thermal comfort to a level of ‘very uncomfortable’ by the 60th min. When the subjects stopped walking and rested in the chamber, the thermal comfort in the Control trial increased to a level of ‘just uncomfortable’ but remained at a level of ‘very uncomfortable’ in the SRBA trial.

The RPE increased markedly with time during the walking session and decreased during the rest session in both the SRBA and Control conditions, as shown in Fig. 8. In the SRBA trial, the RPE levels of the subjects increased from ‘very light’ (9.8) to ‘hard’ (15.3) during the walking session and decreased from ‘hard’ (15.3) to ‘fairly light’ (11.0) during the rest session. Similarly, in the Control trial, the RPE levels of the subjects increased from ‘fairly light’ (10.5) to ‘hard’ (14.5) during the walking session and then recovered to ‘fairly light’ (11.5) at the end of the trial. However, no significant ($p < 0.05$) in terms of RPE between the SRBA and Control conditions was found throughout the trials, indicating that the use of the SRBA did not impose additional exertion on the human body.

In terms of restriction to movement, the subjects in the SRBA and Control trials felt ‘restricted’ to ‘extremely restricted’ and ‘restricted’ to ‘very restricted’, respectively, as shown in Fig. 9. The values of restriction to movement in the SRBA trial were 33.3%, 50.0%, and 85.7% higher than those in the Control trial during the pre-test, test, and post-test phases, respectively. There was a significant difference ($p < 0.05$) in terms of restriction to movement between the SRBA and Control conditions during the walking session, whereas no significant differences ($p > 0.05$) were observed in the pre-test and post-test phases. Hence, restriction to movement was affected not only the use of SRBA but also

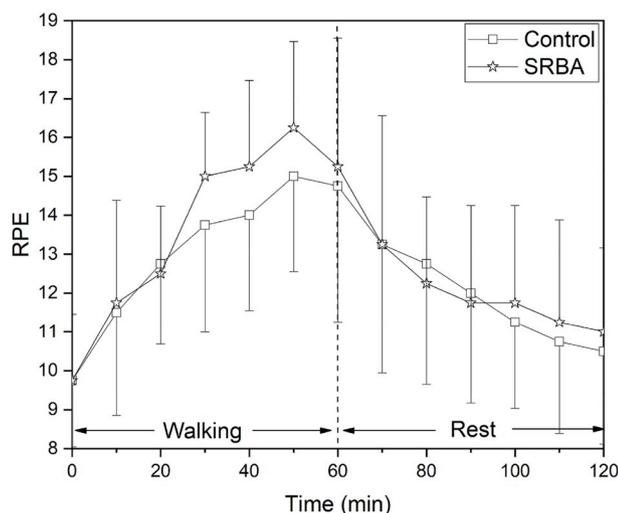


Fig. 8. RPE in SRBA and Control conditions.

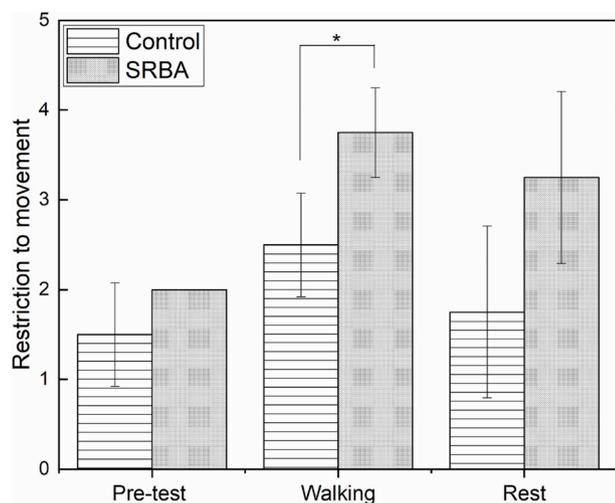


Fig. 9. Restriction to movement in SRBA and Control conditions (*, $p < 0.05$).

work intensity. More specifically, the effect of SRBA on restriction to movement was exacerbated by working intensity.

4. Discussion

4.1. Effect of SRBA on physiological responses

Core temperature was applied as an index of heat strain, and elevated core temperature was associated with reduced thermoregulation and physical performance, onset of fatigue, and increased health risk (Barnekow-Bergkvist et al., 2004). In this study, the core temperature was increased by 2.1 °C in the Control and by 2.5 °C in the SRBA during the exercise session, indicating that subjects reached compensable heat stress (DenHartog et al., 2016). Although there was no significant difference between the two trials in terms of ΔT_c , there appeared to be a tendency among the subjects to exhibit higher ΔT_c values in the SRBA trial than in the Control trial, and the maximum difference was 0.4 °C. The greater core temperature was attributed to higher metabolic rate and lower heat dissipation from the skin to its thermal environment owing to the characteristics of the SRBA, which is heavy, thick, and multi-layered. Several studies (Carballo-Leyenda et al., 2018; Lee et al., 2014) have demonstrated that wearing protective clothing during exercise increased the metabolic rate. Additionally, metabolism had a

significant influence on core temperature (Børsheim and Bahr, 2003; Jay et al., 2008). Based on the increased metabolic rate and restricted heat loss, the subjects continued to store heat and this resulted in heat unbalance occurred, which caused the core temperature, skin temperature, and heart rate to increase continuously during the tests. Even after passive recovery for 1 h, the core temperature could not return to its initial value in both the SRBA and Control conditions, indicating that passive rest was not an effective cooling strategy. In further study, a cooling system will be applied to investigate its effect on thermoregulatory strains.

Skin temperature plays an important role in thermoregulation as peripheral thermoreceptors within the skin communicate with sensory neurons in the hypothalamus which regulates the body temperature (Wit and Wang, 1968). Furthermore, skin temperature is an important index in predicting thermal sensation and thermal comfort (Zhang et al., 2010b). Wearing protective clothing is associated with a thermoregulatory restriction that increases the blood flow rate to dissipate heat from the human body. When the ambient temperature is higher than skin temperature, the human body absorbs heat from its ambient environment and evaporation is the sole avenue of heat dissipation from the skin. However, protective clothing greatly impairs evaporation efficiency. In a previous study, the evaporation efficiency declined by as much as 50% in subjects fully clothed in hot environments (Carballo-Leyenda et al., 2018; Costello et al., 2015; Maley et al., 2017; Montain et al., 1994; Welles et al., 2018). Therefore, the hot and humid environment in this study caused a dramatic decline in evaporative potential, and this phenomenon, combined with the body armor and intense exercise, increased the mean skin temperature to such a high level during exercise that it could not return to its initial value even after passive rest for 1 h.

Heart rate is an important index of cardiovascular health. Constable et al. (1994) found that most subjects ended trials owing to heart rate limitations and not because of having reached ethical rectal constraints. Similarly, Costello et al. (2015) observed that majority of trials (78.7%) were terminated due to subject's heart rate exceeding 90% of their maximum, and only 5.6% due to core temperature in excess of 39 °C. Cardiovascular, rather than thermoregulatory strain, was the limiting factor to work tolerance and performance when wearing heavy, multi-layered, and encapsulating protective clothing (Caldwell et al., 2011; Costello et al., 2015). The peak heart rates of the subjects in the SRBA and Control trials were 169 bpm and 159 bpm, respectively, which were 80–85% of the age-predicted maximum heart rate (maximum heart rate = 220-age), indicating that the subjects experienced serious cardiovascular load during the trials (Horn et al., 2019). However, no significant difference ($p > 0.05$) in terms of heart rate between the two conditions was observed. This finding was consistent with that of a previous study conducted by Larsen et al. (2012). A large variance in heart rate was observed among the subjects, which might have arisen from multiple sources. First, the heart rate was affected by not only the work intensity or clothing of the subject but also other factors, such as food intake, stress, and environmental conditions (Yang et al., 2019). Second, the heart rate was affected by the fitness level of the subject, increased fitness level has been correlated with a lower heart rate during exercise.

The subjects had significantly higher ($p < 0.05$) oxygen consumption values in the SRBA condition than in the Control condition. Specifically, the use of the SRBA resulted in 37.1% greater oxygen consumption at the 60th min compared with that in the Control condition, which agreed well with a previous study (Carballo-Leyenda et al., 2018) wherein protective clothing caused an increase of 20–45% in oxygen consumption. Furthermore, another study showed that oxygen uptake in the use of body increased by 11.9% at slow paces and 17.2% at moderate paces (Ricciardi et al., 2008). This was explained by the increase in weight, which was related to the increased heart rate and metabolic rate. However, no significant difference ($p > 0.05$) was found between the SRBA and Control conditions in terms of oxygen consumption during the

rest session. This can be explained based on the findings from the literature (Abe et al., 2004; Keren et al., 1981), wherein oxygen consumption during walking increased with increasing load and was proportional to walking speed.

Linear regression was applied to explore the relationship between heart rate and oxygen consumption during the waking session, as depicted in Fig. 10. A strong linear association between heart rate and oxygen consumption was noted in both the SRBA and Control conditions, which agreed with the results of Yang et al. (2019) who found a strong relationship between heart rate and oxygen consumption in daily activities and at work. It should be noted that the slope of the graph of heart rate versus oxygen can be influenced by the characteristics of muscular work, such as small or large muscle groups, and static or dynamic components.

4.2. The effect of SRBA on perceptual responses

The maximum difference in terms of RPE between the SRBA and Control trials was 1.3 points during the exercise, while the RPE values in both trials were almost identical. This can likely be explained based on clothing weight and work intensity. Ricciardi et al. (2008) found that the values of RPE in the use of body armor were 2.1 and 2.4 points greater than those without body armor at slow and moderate paces, respectively. In contrast, no difference in RPE was observed when the load was increased from 0 to 15% in another study (Quesada et al., 2000). It was found that a probable influence of the increase in core temperature on fatigue in the literature (Constable et al., 1994). The relationship between heart rate and RPE is shown in Fig. 11, and the trend agreed well with the findings of Ricciardi et al. (2008). Furthermore, high metabolic demand resulted in physical fatigue and increased risk of cardiovascular diseases (Krause et al., 2015).

Minimal differences in terms of thermal comfort and thermal sensation were observed between the SRBA and Control trials. This was in line with a study performed by Pyke et al. (2015) who observed no significant difference ($p = 0.58$) in terms of thermal comfort and sensation between ensembles. The subjects felt 'hot' to 'very hot', and this might have been a consequence of the hot and humid environmental conditions and high metabolic rate during exercise. The period of passive rest only resulted in a limited reduction in thermal sensation and thermal comfort. The thermal sensation was primarily related to skin temperature, and thermal comfort was closely related to core temperature (Kato et al., 2001). Additionally, thermal comfort was affected by the use of an additional garment with additional weight (Teunissen et al., 2014). In a study by Savage et al (2014), a weak correlation between core temperature and the thermal sensation was found in

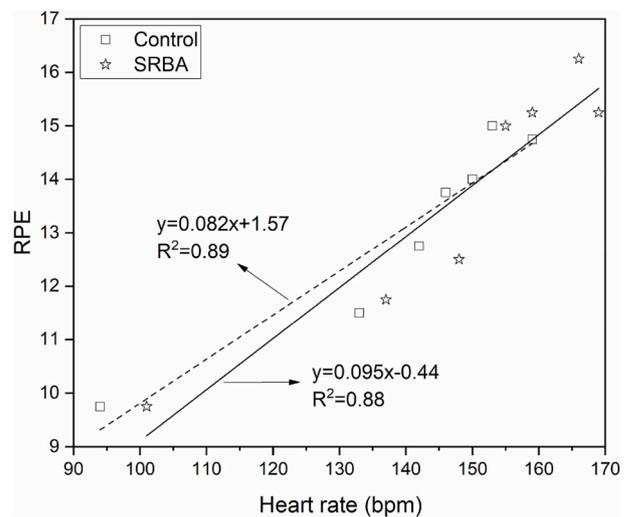


Fig. 11. Correlation between heart rate and RPE.

different environmental conditions. Zhang et al. (2010a,b) demonstrated that thermal sensation and thermal comfort were affected by skin temperature, core temperature, and its change rate of core and skin temperatures. Savage et al. (2014) found that metabolic rate was the driver of core temperature whereas skin temperature was the driver of thermal sensation.

During exercise, the subjects were rated with significantly higher ($p < 0.05$) restriction to movement in the SRBA trial than that in the Control trial. This can be attributed to the heaviness and bulk of the body armor. To ensure increased resistance protection, the weight and bulk of the body armor were inevitably higher, thereby significantly impairing the mobility, thermal comfort, and work efficiency of the wearer (Boorady et al., 2013; Sobeih et al., 2006). It has been reported that wearing protective clothing could impair body balance and causes musculoskeletal injuries (Park et al., 2014).

The effects of the use of the SRBA on physiological and perceptual responses were investigated in this study; however, a few limitations remain. The subjects were selected for treadmill tests in a climate chamber under ideal working conditions, which were different from the actual working environments of wearers such as military personnel, police, and first responders. Moreover, the physiological and perceptual responses were affected by numerous factors, such as biomechanical factors, walking speed, protective clothing, and environmental conditions. However, limited work activities and environmental conditions were selected in this study. Additionally, the sample size in this study was small and only five participants performed the tests. In further studies, it is necessary to recruit more volunteers and perform more human trials pertaining to the use of SRBA in various situations to gain a deeper understanding of the physiological and perceptual responses of the wearers.

5. Conclusions

In this study, the effects of SRBA on the physiological responses and perceptual parameters were investigated through human trials entailing both walking and rest sessions in a climate chamber. The subjects wearing SRBA had increased values of core temperature, mean skin temperature, heart rate, and oxygen consumption during the exercise session. Furthermore, the subjects exhibited significantly greater oxygen consumption in the SRBA trial than that in the Control trial, but no significant difference was observed between the two trials in terms of other physiological parameters throughout the tests. In the case of perceptual responses, the two trials did not differ in terms of thermal, thermal comfort or RPE, but differed significantly in terms of restriction

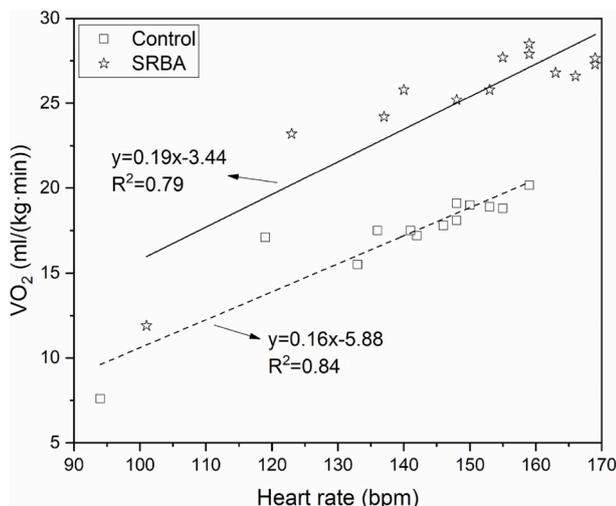


Fig. 10. Correlation between heart rate and oxygen consumption.

to movement during walking. In future research, more volunteers will be recruited, and field studies will be conducted to better understand more successfully the influence of SRBA on the physiological and perceptual responses during occupational activities in real working situations.

Declaration of competing interest

There are no conflicts of interest.

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