Thermoregulatory responses of junior lifesavers wearing protective clothing

Wade H. Sinclair *, Melissa J. Crowe, Warwick L. Spinks, Anthony S. Leicht

Institute of Sport and Exercise Science, James Cook University, Queensland, Australia

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KEYWORDS
Child; Exercise; Heat; Protective clothing; Body temperature regulation

Summary This study investigated the influence of protective clothing worn to prevent marine stinger envenomation on the thermoregulatory responses of pre-pubescent surf lifesavers exercising in situ under hot and humid conditions (27 °C, 78% relative humidity). Participants performed beach and water activities typically associated with junior surf lifesaving competition in a randomised cross-over design on two separate occasions 7 days apart: one wearing a full-length Lycra stinger suit (S) and one wearing normal swimwear (SW). Skin (T SK) and core (T C) body temperatures, skin blood flow (SKBF), heart rate (HR), body mass, thermal comfort and perceived effort were assessed pre-, mid- (following beach activities) and post-exercise (following water activities). Sweat rates were compared between S and SW. T C was greater following beach activities for S (37.78 °C ± 0.06) compared to SW (37.60 °C ± 0.07; p < 0.05) and male participants experienced greater T C (37.97 °C ± 0.09) than their female counterparts (37.71 °C ± 0.07 °C). T SK following both the beach and water activities were lower than pre-exercise (p < 0.05). SKBF was significantly increased for calf across time (p < 0.01). Male participants experienced a higher HR for S compared to female participants (p < 0.01) while the opposite applied to SW (p < 0.01). There were no gender or between-condition differences for sweat rate or perceived effort. There was evidence of heat storage while stinger suits were worn during beach activities in the absence of any differences in exercise intensity or sweat rate. The results of the present study suggest that the stinger suits should be limited to water-based activities.

Introduction

Marine stinger species are endemic along the north Australian coastline between the warmer months of October and May and are known to initiate severe systemic, noxious and immunological pathologies or inflict death within minutes.1 The north Queensland marine stinger season parallels surf lifesaving activities in the region. As a result, the bathing public are required to swim within stinger-resistant netted enclosures and it is mandatory for junior

* Corresponding author.
E-mail address: Wade.Sinclair@jcu.edu.au (W.H. Sinclair).
surf lifesavers to wear full-length protective clothing (stinger suits) during training and competitive activities. In addition to high ambient temperatures and humidity during this period, stinger suits present an increased possibility of heat-related illness in these children, while competing and during impromptu play between competitive events.\(^2,^3\)

During exposure to extreme climatic heat, the thermoregulatory capabilities of children are severely disadvantaged compared to adults, thereby increasing their risk of experiencing heat-related illness.\(^3−^6\) The ability of children to thermoregulate while exercising in thermoneutral environments is similar to that of adults albeit via differing routes.\(^7,^8\) However, this thermoregulatory ability is deficient when exposed to extreme environmental conditions.\(^4\) When compared to adults, children have a greater surface-area-to-body mass ratio\(^4\) and rely more on conduction, convection and radiation than adults which can become a liability once ambient temperatures exceed that of the skin.\(^9\) Under these conditions, heat is absorbed from the environment imposing additional thermoregulatory stress on children, thereby increasing their susceptibility to an increased core body temperature (\(T_C\)) and potential development of heat-related illnesses. Children exercising in hot environments are at a further disadvantage compared to adults because of differing body composition,\(^9\) smaller absolute blood volume,\(^7,^10\) lower cardiac output,\(^10\) greater metabolic heat production kg\(^{-1}\) body mass during work\(^4\) and a less efficient sweating mechanism.\(^4\) Additionally, exercising while wearing close-fitting clothing in hot environments can increase \(T_C.\)\(^2\) Consequently, pre-pubescent surf lifesavers in northern Australia are at an increased risk of developing heat-related illness because of physiological limitations as well as those imposed by the environment and the protective clothing requirements of their sport.

This study evaluated the thermoregulatory responses and cardiovascular strain of pre-pubescent surf lifesavers competing in beach activities in situ under hot and humid conditions while wearing full-length stinger suits. While participants competed in junior surf lifesaving beach and water activities, the primary focus of the study was to evaluate the influence of stinger suits on participants competing in beach activities, as previous research has shown significant heat loss from the body during immersion in water.\(^11,^12\) It was hypothesised that pre-pubescent surf lifesavers exercising in stinger suits would experience an increased thermoregulatory strain compared to wearing normal swimwear while competing in surf lifesaving beach activities.

**Methods**

**Participants**

Pre-pubescent surf lifesavers (male, \(n=7;\) female, \(n=13\)) were recruited from north Queensland surf lifesaving clubs. The descriptive characteristics of the participants are presented in Table 1. Participants (aged 7–12 years) were classified as pre-pubertal based on previous research that employed the Tanner stages for assessing maturation which identified pre-pubertal children to be <12.2 years.\(^13,^14\) Participant and parental written informed consent was obtained and the study approved by James Cook University Human Research Ethics Sub-Committee and Surf Life Saving Queensland in accordance with the 1964 Declaration of Helsinki. Participants were immediately withdrawn from the study if exercising HR > 95% age-predicted HR\(_{max}\), \(T_C > 39°C\) or any signs or symptoms of heat-related illness were evident.\(^15\)

**Experimental procedures**

Participants attended two randomised cross-over trials 7 days apart; one wearing a full-length stinger suit (S) and one wearing normal swimwear (SW). SW consisted of either one-piece or bikini-style swimwear for the females and one-piece swimming briefs for males. The stinger suits comprised a one-piece protective stinger suit of swimsuit material (82% nylon, 18% Lycra\(^\text{®}\)) with only the head, feet and hands exposed. Each trial consisted of participants competing in beach activities followed by water activities in the same order and identical to those conducted during normal training sessions.

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**Table 1** Descriptive characteristics for male, female and all participants

<table>
<thead>
<tr>
<th></th>
<th>(n)</th>
<th>Age (years)</th>
<th>Body mass (kg)</th>
<th>Height (m)</th>
<th>(A_0) (m(^2))</th>
<th>(A_0M) (cm(^2) kg(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>7</td>
<td>9.1 ± 0.4</td>
<td>32.0 ± 1.1</td>
<td>1.36 ± 0.03</td>
<td>1.10 ± 0.03</td>
<td>346.27 ± 3.07</td>
</tr>
<tr>
<td>Female</td>
<td>13</td>
<td>9.9 ± 0.4</td>
<td>34.8 ± 2.2</td>
<td>1.37 ± 0.03</td>
<td>1.15 ± 0.04</td>
<td>337.81 ± 7.85</td>
</tr>
<tr>
<td>All</td>
<td>20</td>
<td>9.7 ± 0.4</td>
<td>33.8 ± 1.9</td>
<td>1.37 ± 0.02</td>
<td>1.13 ± 0.04</td>
<td>340.77 ± 6.54</td>
</tr>
</tbody>
</table>

Values are presented as mean ± S.E.; \(A_0 =\) surface area; \(A_0M =\) surface-area-to-body mass ratio.

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Beach activities included beach flags (7–12 years; 4–6 multiple 15-m sprints competing for a piece of rubber hose with one person eliminated each round until a winner is identified); 70-m beach sprint (7–12 years) and an age-group 70-m beach relay (9–12 years). Water activities commenced and finished on the beach with participants rounding buoys placed at various lengths within the stinger resistant enclosure. Water activities included a 20-m wading race (7–10 years), an age-group 40-m wading relay (7–10 years), 150-m surf swim race (9–12 years), 150-m surfboard paddle race (9–12 years) and Ironman and Ironwoman races (11–12 years, consisting of a 150-m swim and 150-m surfboard paddle with 40 m of intermittent beach running). Swim distances were typical of those used in training sessions held within stinger resistant enclosures. Rest periods between activities ranged between 5 and 15 min with 20 min between beach and water activities.

Experimental protocols

Participant body mass was recorded to the nearest 0.1 kg with participants wearing swimwear only (Tanita TBF-521, Tanita Corporation, Tokyo). Height was recorded to the nearest 0.01 m, using a portable, wall mounted stadiometer (Handy Height Scale, Mentone Educational Center, Australia). Surface area (A
d) and surface-area-to-body mass ratio (A
dM) were calculated via standard equations.16 Blood pressure (BP) and HR were measured using an electronic sphygmomanometer (Nissei DS-157, Japan) and HR monitor (Polar S610 HR Monitor, Polar Electro Oy, Finland), respectively.

Sweat rate was determined via body mass changes and water consumed and expressed relative to time (mLh\(^{-1}\)). During the first trial, participants consumed water ad libitum while in the assessment area with the time and volume of water consumed recorded so that participants could be issued with the same volume at identical times during the second trial in order to minimise fluid consumption effects.

looseness1 TC was assessed via tympanic membrane infrared thermometry (FirstTemp 2000A, Intelligent Medical Systems, USA) from the participant’s right ear and in an area sheltered from airflow by the same researcher.17 Prior to commencement of this study, the accuracy of the tympanic thermometer was confirmed as ≤0.1°C by comparing skin temperature assessments between the unit (using the ‘surface’ setting) and skin surface temperature probes (SST-1, Physitemp Instruments Inc., NJ, USA). Previous research has shown the FirstTemp 2000A to record tympanic temperatures within an average of 0.13°C of rectal temperature.18

Following the removal of the stinger suit, and surface water and sand from the skin, T\(_{SK}\) was measured via skin surface temperature probes. SKBF was measured by laser Doppler flowmetry (ML191 Blood FlowMeter, PowerLab AD Instruments, Australia) and four-channel PowerLab (PowerLab/4SP, AD Instruments, Australia). Blood flowmeter output was 4 mV for each recorded blood perfusion unit at a sampling rate of 10 Hz. SKBF data were collected using Chart for Windows software (Chart v4.0.1, AD Instruments, Australia) and data points were obtained from 5 s of continuous segments with minimal artefact noise for each site. Four anthropometric landmarks (forehead, back, forearm and calf) were marked on the participant’s right side prior to commencing competition activities to enhance the reproducibility of T\(_{SK}\) and SKBF measurements.

Participant perceptions of exercise effort was assessed via the 10-point Children’s Effort Rating (CERT) Scale.19 Environmental parameters (dry and wet bulb, black globe, %RH and WGT) were logged for the duration of the trials (CR10X Measurement and Control System, Campbell Scientific Pty. Ltd., Australia).

Statistical analyses

Data analysis was conducted using the Statistical Package for Social Sciences (v.11. SPSS, Chicago, USA). Distribution of data was initially assessed using the Kolmogorov–Smirnov test of normality with all skewed data transformed.20 Analysis was conducted via three-way repeated measures ANOVA (condition × time × gender) of condition (S or SW) × time (pre-, mid- and post-exercise) × gender (M/F). Two-way repeated measures ANOVA (time × gender) was conducted for sweat rate data. Post hoc analysis was conducted using the Tukey test. Where all assumptions of ANOVA were not met, nonparametric comparisons were performed via the Friedman Test with subsequent post hoc analysis by Nemenyi’s test. A one-way ANOVA or the nonparametric Wilcoxon Signed Ranks test was conducted to assess between-gender differences for age, height, body mass, A
d and A
dM. Alpha was set at 0.05 and all values are presented as mean ± S.E.

Results

Environmental conditions for the trials are presented in Table 2 with wet bulb (T\(_{WB}\)) and wet bulb
Table 2 Environmental conditions experienced by participants during surf lifesaving activities on days 1 and 2

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry bulb (°C)</td>
<td>27.3 ± 0.3</td>
<td>27.8 ± 0.3</td>
</tr>
<tr>
<td>Wet bulb (°C)</td>
<td>24.6 ± 0.1</td>
<td>24.9 ± 0.3**</td>
</tr>
<tr>
<td>Black globe (°C)</td>
<td>28.9 ± 0.6</td>
<td>30.7 ± 0.7</td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>81.6 ± 2.4</td>
<td>76.8 ± 1.5*</td>
</tr>
<tr>
<td>WBGT (°C)</td>
<td>25.7 ± 0.1</td>
<td>26.3 ± 0.3*</td>
</tr>
</tbody>
</table>

Values are presented as mean ± S.E.; *p < 0.05, **p<0.01 significantly different to Day 1.

Discussion

The results suggest an increased thermoregulatory strain on pre-pubescent surf lifesavers wearing a stinger suit and exercising in warm, humid environments. Participants experienced higher $T_c$ globule temperature (WBGT) greater and %RH lower for day 2 compared to day 1 ($p < 0.05$).

$T_c$ for S (37.78 °C ± 0.06) was significantly greater compared to SW (37.60 °C±; $p < 0.05$) when combined for gender and time. Following the beach activities, $T_c$ was higher for S (37.81 °C ± 0.06) compared to SW (37.52 °C ± 0.08; $p < 0.01$) and significantly increased for S ($p < 0.01$) and decreased for SW ($p < 0.01$) from pre-exercise. $T_c$ after the water activities for both S and SW was lower than both pre-exercise and following the beach activities ($p < 0.01$). $T_c$ was significantly greater following the beach activities for male participants compared to pre-exercise values and female $T_c$ after the beach activities (Fig. 1).

$T_{SK}$ at all sites was significantly lower than pre-exercise after both the beach ($p < 0.05$) and water activities ($p < 0.05$; Table 3). There was no effect of condition or gender on $T_{SK}$ ($p > 0.05$).

$SK_{BF, CALF}$ following the beach events (39.59 ± 2.76 mV) was increased compared to baseline (29.22 ± 3.15 mV; $p < 0.01$) and was significantly lower following the water events (27.61 ± 2.18 mV; $p < 0.01$). No differences were found for $SK_{BF}$ at any of the other sites.

Male HR for S was significantly greater compared to SW and females for S (Fig. 2). Female HR for SW was significantly greater than S and males for SW (Fig. 2).

No differences were identified for the effects of condition, time or gender for sweat rate which averaged 195 mL h$^{-1}$ (0.58% initial body mass h$^{-1}$) and 126 mL h$^{-1}$ (0.37% initial body mass h$^{-1}$) for SW; $p > 0.05$). No differences were identified for CERT between S (4.14 ± 0.38) and SW (3.63 ± 0.41; $p > 0.05$).

Figure 1 Core body temperature (°C) for male and female participants with (S) and without (SW) stinger suits prior to (pre-exercise) and following beach activities (mid-exercise). Values are presented as mean ± S.E. *$p<0.01$ greater than female S; **$p<0.01$ greater than opposite condition for same gender.

Figure 2 Heart rate (b min$^{-1}$) for male and female participants with (S) and without (SW) stinger suits when pooled for time. Values are presented as mean ± S.E. *$p<0.01$ greater than opposite gender; **$p<0.01$ greater than opposite condition for same gender.

Table 3 Forehead, back, forearm and calf skin temperatures (°C) for all participants prior to (pre-exercise) and following beach activities (mid-exercise) and following water activities (post-exercise)

<table>
<thead>
<tr>
<th></th>
<th>Pre-exercise</th>
<th>Mid-exercise</th>
<th>Post-exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forehead</td>
<td>34.6 ± 0.1</td>
<td>33.7 ± 0.1$^b$</td>
<td>33.5 ± 0.2$^b$</td>
</tr>
<tr>
<td>Back</td>
<td>33.3 ± 0.1</td>
<td>32.8 ± 0.2$^a$</td>
<td>32.1 ± 0.2$^{a,b}$</td>
</tr>
<tr>
<td>Forearm</td>
<td>34.6 ± 0.1</td>
<td>33.7 ± 0.1$^b$</td>
<td>33.5 ± 0.2$^b$</td>
</tr>
<tr>
<td>Calf</td>
<td>32.2 ± 0.1</td>
<td>31.7 ± 0.2$^a$</td>
<td>30.2 ± 0.1$^{a,b}$</td>
</tr>
</tbody>
</table>

Values are presented as mean ± S.E. $^a_p<0.05$. $^b_p<0.01$ significantly lower than pre-exercise. $^c_p<0.01$ significantly lower than mid-exercise.

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Children in protective clothing

...while wearing the full-length protective stinger suits during the beach activities compared to pre-exercise. However, the observed increase (0.29 °C) is not considered biologically important. Conversely, significantly lower $T_C$ and $T_{SK}$ for both S and SW following the water activities was most likely because of an enhanced thermal gradient in the water resulting in an increased conductive and convective heat transfer between the core and the skin and the skin-to-water boundary, respectively.\(^{11,21,22}\) Although the incidence of $T_C \geq 38^\circ C$ following beach activities (32% for S and 11% for SW) parallels previous research,\(^7,8,14,23-25\) children in those studies were exposed to greater climatic heat stress (34–49 °C, 18–45%RH) than those in the present study.

Tympnic infra-red thermometry has been described as problematic.\(^{26,27}\) However, the coefficient of variation ($c_v$) for $T_C$ in this study ($c_v \leq 0.93\%$) was found to be comparable to those previously reported for rectal temperature ($c_v \leq 0.97\%$) and tympnic $T_C$ ($c_v \leq 1.07\%$) under hot environmental conditions.\(^{28}\) The higher $T_C$ and HR identified in the male participants parallels previous research\(^{28,29}\) but contrasts with other studies in which females had significantly higher HR when exercising,\(^{10}\) particularly under hot conditions.\(^7\)

Previously, lower $T_C$ for females exercising in hot and humid environments has been attributed to their greater $A_pDM$ or lower lean muscle mass.\(^{29}\) In individuals of similar body mass, greater thermal stress is required to elevate $T_C$ for low adiposity levels due to the respective specific heat of adipose tissue (1.67 kJ kg\(^{-1}\) °C\(^{-1}\)) and fat free mass (3.35 kJ kg\(^{-1}\) °C\(^{-1}\)).\(^9\) A plausible explanation for higher $T_C$ in male participants in the present study may be higher adiposity levels than in their female counterparts. Pre-pubertal girls have lower % body fat than adult females and pre-pubertal boys have slightly higher levels of adiposity than adult males.\(^9\) Although body composition was not assessed in the current study, $A_pDM$ was not significantly different between genders. When matched for $A_pDM$ and fitness levels, females maintain similar or lower $T_C$ and lower HR than males,\(^{28}\) suggesting male adiposity levels as causative of the higher $T_C$ in the present study. Furthermore, higher male HR suggests males may have been more competitive during the beach activities than the females,\(^{30}\) resulting in an increased exercise intensity and thus increasing metabolic heat production. Consequently, male participants may have experienced increased sympathetic activity initiating vasodilation to meet the increased thermoregulatory demand.\(^{31}\) Another contributing factor could also be the resultant higher $T_C$ having a direct influence on the sinoatrial node.\(^{31}\) Previous research on the thermoregulatory responses of pre-pubertal children exercising in hot environments is inconclusive and warrants further investigation.

Children experience a reduced sensitivity in initiation of the sweating response with increases in $T_C$.\(^9\) However, the absence of a significant decrease in $T_{SK}$ in participants in the present study suggests cooler $T_{SK}$ resulted from sweat evaporating from the skin or sweat absorbed in the stinger suit cooling the skin surface. Sweating is an effective heat loss mechanism for children during mild heat exposure.\(^6\) However, childrens sweat rate can be ineffective during periods of combined heat and exercise stress when compared to adults.\(^7,32\) In addition, the major contributor to environmental stress is %RH, with high %RH compromising the evaporative heat loss potential of sweat.\(^{33}\) The humid conditions experienced in the present study (76.8–81.6%RH) limited the evaporative capacity of the participants exemplified by sweat rates being indicative of non-acclimatised children (260–300 mL h\(^{-1}\)) rather than children who have resided in the region for 7.0 ± 0.8 years and would therefore be acclimatised.\(^8,14,23\) Sweat rates in the present study ranged between 0.4 and 0.6% initial body mass h\(^{-1}\) potentially increasing $T_C$ by 0.2 °C and/or HR by 3–5 beats min\(^{-1}\),\(^34\) thereby exacerbating thermoregulatory and cardiovascular strain. A loss of 0.3% initial body mass h\(^{-1}\) results in greater increases in the $T_C$ of children compared to adults for similar levels of hydration.\(^{35}\) Therefore, the combined thermal stress, exercise intensity and sweat loss in the current study was sufficient to elicit an increased thermoregulatory and cardiovascular strain.

Previous studies conducted indoors under controlled climatic conditions have occurred in the near absence of any airflow.\(^7,8,14,23-25\) Airflow would substantially influence convective and evaporative heat loss.\(^36\) The $T_{SK}$ results for all sites in the present study were significantly lower following both the beach and water activities possibly as a consequence of airflow experienced (≥6.5 km h\(^{-1}\) ± 2.4) prior to the assessment of $T_{SK}$\(^{36}\) aiding evaporative heat loss or conductive heat loss between the skin and water.\(^{11,21}\) Caution should be extended to comparisons between indoor and outdoor studies because $T_C$, $T_{SK}$, HR, perceived exertion and sweat rate are all significantly influenced by the velocity of circulating air.\(^{36,37}\)

Taken together, the present results suggest that full-length protective stinger suits worn by junior surf lifesavers in north Queensland promote heat storage when worn while competing in beach activities typically associated with surf lifesaving.

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competition. Despite all participants being asymptomatic of heat-related illness during both trials, the higher $T_c$ for participants while wearing stinger suits and in the absence of any differences in sweat rate and perceived exercise intensity is potentially related to heat stored during stinger suit use.\textsuperscript{38} Therefore, these junior athletes are at an increased risk of developing heat-related illness because of higher $T_c$ resulting from ambient environmental conditions, poor hydration status, clothing worn and intensity of the exercise undertaken.\textsuperscript{2,3,5} Higher $T_c$ and HR in males wearing stinger suits suggest they experienced additional cardiovascular and thermoregulatory strain during beach activities compared to females. Collectively, the present results suggest that protective stinger suits should be limited to water-based activities rather than a sun protection role on the beach and caution extended to environments hotter or more humid than those assessed in this study.

**Practical implications**

- During beach activities, wearing stinger suits may place pre-pubertal surf lifesavers at an increased risk of developing heat-related illnesses.
- Pre-pubertal boys exhibit greater physiological stress than pre-pubertal girls while wearing stinger suits under hot and humid conditions.
- As a safeguard for junior surf lifesavers, stinger suits use should be confined to water-based activities.

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**References**


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