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ORIGINAL ARTICLE

Thermoregulatory sex differences among surfers during a simulated surf session

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Abstract
The purpose of this study was to test the hypothesis that under controlled surf conditions, sex differences in skin temperature exist, but core temperature would not vary between sexes when performing a simulated surf session while wearing a 2-mm wetsuit. Twenty male and 13 female surfers engaged in a 60-min simulated surf protocol using a custom 2-mm wetsuit in an Endless Pool Elite Flume with water temperature set to 15.6 °C. Participants were instrumented with a heart rate monitor, eight skin temperature sensors, and a disposable sensor for measurement of core temperature. The surf simulation consisted of paddling, duck-diving and stationary activities at three paddling speeds (1.2, 1.4 and 1.6 m/s). Participants were asked their thermal sensation periodically during the protocol, and all data were collected at 1-min intervals. Results indicated no significant differences in core temperature between males (37.31 ± 0.35 °C) and females (37.32 ± 0.48 °C, $p = 0.995$). Upper arm and thigh skin temperatures were significantly lower in females (27.45 ± 1.04 °C and 23.53 ± 0.78 °C, respectively) than males (28.61 ± 1.32 °C and 24.73 ± 0.68 °C; $p = 0.012$ and $p = 0.000$, respectively). Conversely, skin temperatures in the abdomen were significantly lower in males (26.57 ± 1.44 °C) than females (27.75 ± 1.50 °C; $p = 0.035$). Meanwhile, perceptual data were inconclusive. The results suggest that although regional differences in skin temperature may exist between male and female surfers, they may be too small to translate into perceptual differences and are unnecessary when considering wetsuit design.

Keywords Skin temperature · Action sports · Thermoregulation

1 Introduction

Surfing has become increasingly popular with ~ 37 million people participating recreationally and competitively worldwide [1]. These figures are expected to increase as surfing makes its debut in the 2020 Summer Olympics. Surfing exposes the body to both water and air. These two mediums have different convective heat loss properties and subsequently create a thermoregulatory challenge for surfers [2]. Wetsuits are often utilized to reduce convective heat loss during surfing.

Wetsuits are typically made from neoprene, a polymer-based closed-cell foam with knit jersey laminated to one or both sides of the foam to create a thermal barrier protecting the skin from cold water stress. Neoprene may also mitigate heat loss for surfers by allowing small amounts of water to filter through the wetsuit, creating a thin layer of warmer water between the skin and neoprene [3]. However, to effectively protect surfers from cold environmental conditions, wetsuit design must also consider the unique activity profile of surfers and sex differences.

Understanding surf activity profiles is important in wetsuit design because water exposure varies across the regions of the body during surfing and will influence convective heat loss patterns [4]. Surfers typically spend under 10% of the time actually riding waves, with about half the time paddling and the remaining 40% stationary [5–11]. Depending on the surf activity, rates of convective heat loss through air and water will vary. Water is 25% more conductive than air, and therefore convective heat loss will be three to five times greater at regions of the body with increased water exposure,

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such as the legs, abdomen, forearms and hands [2, 12–14]. During a typical surf session, the regional differences in skeletal muscle activity in addition to water exposure create uneven skin temperatures across the body [15]. This may result in performance deficits since reductions in regional surface skin temperatures exhibited from increased water exposure are associated with reductions in skeletal muscle performance, such as force production and power output [16–18]. During cold stress, a decrease in extremity skin temperatures will also impact core temperature at the onset of hypothermia [4]. Thus, it is imperative to understand patterns of heat loss during surfing to better inform wetsuit design and increase performance and safety.

Thermoregulatory sex differences may also be an additional component that influences wetsuit design for surfers. With wetsuit materials and design remaining relatively unchanged over the last 60 years, design esthetic and anatomical differences, such as bust and hip ratios, are the primary factors dictating current wetsuit models and design differences between sexes. Yet recent research suggests differences in regional skin temperatures between male and female surfers [15, 19]. These two field studies suggest that females exhibit colder skin temperatures at the low back and forearm than males during a 40-min recreational surf session while wearing a 2-mm wetsuit [15, 19]. However, it is important to note that reported differences in environmental factors (i.e. ambient air temperature, wind, relative humidity, water temperature, swell size, etc.) between the two studies may have contributed to these regional differences in skin temperature between sexes. Physiological differences may be another plausible explanation for the reported sex differences in skin temperature. Specifically, differences in body surface area (influencing heat exchange rates), vasoconstrictive responses, reproductive hormones and body composition have all been reported to contribute to thermoregulatory sex differences [4, 20–24]. It also remains unclear if these potential sex differences in skin temperature result in varying reductions in core temperature between sexes. Therefore, the purpose of this study was to compare body composition, skin and core temperatures of females and males in a 2-mm wetsuit during a well-controlled simulated surf session. We hypothesized that regional differences in skin temperature would exist between sexes, but this would not translate to core temperature differences between sexes.

2 Methods

2.1 Participants

Inclusion criteria required participants to be healthy, with no digestive tract disorders and a minimum of 5 years short-board surf experience to ensure adequate surf activity skills. Exclusion criteria limited the age of participants to between 18 and 45 years to reduce hormonal effects on thermoregulation, in addition to restricting body mass between 50 and 86 kg to reduce variability in water surface area exposure. Three participants (97.23 kg and 92.53 kg males; 42.45 kg female) did not meet the weight criteria, but their data were still included as heart rate, skin and core temperatures fell within ± 1 Standard Deviation from the mean, and they were not deemed as outliers as determined by Tukey's Boxplot Method [25]. Based upon previous thermoregulation surf research and to obtain significant differences in skin temperature between sexes, the aim of the study was to recruit an equal number of male and female surfers ($n = 20$ males, $n = 20$ females) [15, 19]. However, the advanced nature of the surf simulation and required skillset of shortboard surf experience made it hard to find eligible female participants. Therefore, thirty-three healthy, active participants ($n = 13$ females, $n = 20$ males; Table 1) between ages 18 and 42 were recruited for the study. The percentage of male and female surfers recruited for this study is reflective of the national recreational surf population [26]. Participants were asked to properly hydrate 24 h before testing (0.47 L of water before bed and 0.47 L of water 1–1.5 h before testing). Additionally, they were instructed to refrain from intense exercise 12 h before testing and from eating 3 h before testing. Upon arrival, participants gave their informed written consent to procedures approved by the Institutional Review Board at California State University, San Marcos (Protocol #1302166) along with completing an AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire, Surfing and Physical Activity Questionnaire and a Dietary Composition Questionnaire (Appendices I–III). Female participants were required to include additional health history information (i.e. menstruation cycle and contraception use).

Table 1 Subject characteristics

	Male ($n = 20$)	Female ($n = 13$)	Total ($n = 33$)
Age (years)	26.15 ± 4.45	25.69 ± 7.65	25.97 ± 5.81
Height (cm)	177.36 ± 6.69	169.2 ± 6.18	174.14 ± 7.57
Weight (kg)	77.57 ± 17.82*	60.42 ± 8.20	70.81 ± 16.92
Body surface area (m^2)	1.94 ± 0.21*	1.68 ± 0.14	1.84 ± 0.23
Mean heart rate during surf simulation (bpm)	98.40 ± 16.97	102.3 ± 19.33	99.94 ± 17.74
Body fat (%)	13.14 ± 3.70*	18.62 ± 5.84	15.29 ± 5.32

*Denotes significant differences between sexes at $p < 0.05$. Data expressed as mean ± SD

2.2 Protocol

Following the completion of informed consent and questionnaires, participant's body composition and mass were measured using an InBody 770 device (InBody USA, Cerritos, CA). The InBody is a multi-frequency bio-electrical impedance device that has been validated against both dual-energy X-ray absorptiometry and a four-compartment body composition model with an accuracy of ± 1.0% for body fat, 0.34 kg for fat mass and 0.87 kg for fat-free mass [27, 28]. The participant's total and regional body fat and lean tissue mass were recorded.

Immediately afterward, participants ingested a CorTemp Disposable Body Temperature Sensor (HT150002; HQInc, Palmetto, FL) that had an accuracy of ± 0.1 °C with 0.24 L of water, at least 60 min before the surf simulated protocol to ensure accurate core temperature readings. Immediately after core temperature pill ingestion, participants sat in a temperature-controlled room ranging from ~ 18.3 to 23.9 °C to acclimatize for one hour. Twenty minutes before testing, eight 1-Wire Thermochron iButton skin temperature sensors (type DS1921G; Maxim Integrated/Dallas Semiconductor Corp., USA) with an accuracy of ± 0.5 °C were placed on the participant's right side at the listed locations: chest (skin of superior pectoralis major), back (skin of rhomboid), upper arm (skin of lateral tricep brachii), abdomen (skin of inferior rectus abdominis), low back (skin of inferior portion of latissimus dorsi), forearm (skin of flexor carpi radialis), thigh (skin of lateral vastus laterali), and calf (skin of medial gastrocnemius). Thermistors were numbered (1–8) to ensure the same location placement across all participants and were adhered to the skin with a 6 × 7 cm, 3 M Tegaderm Film (Nexcare™ Tegaderm™, USA). The participant also wore a Polar T31-coded heart rate monitor (Polar Electro Inc., Kempele, Finland) across the sternum that recorded with an accuracy of ± 1 bpm.

Following instrumentation participants were fitted into a full-length black, custom 2-mm wetsuit (Hurley, USA; not commercially available) that utilized glued and blind-stitched seams instead of traditional 3-needle flatlock to reduce the amount of water entering the wetsuit during the simulation. Additionally, wetsuits were fitted to common patterns designed for males and females therefore making wetsuits fit differently between sexes. Sizing for each participant was determined by a height and weight size-chart provided by the wetsuit manufacturer. Males did not wear a bathing suit underneath the 2-mm wetsuit while most females wore a 2-piece bathing suit. The swimsuits worn by the female participants did not interact with the skin thermistors.

Next, the participant's mass-to-surfboard volume predetermined the standardized surfboard used for the protocol to ensure equal water surface area exposure. Before testing, the water temperature in an Elite Endless Pool flume (Commercial Elite Endless Pools®; Aston, PA) was set to 15.6 °C, while percent-relative humidity and ambient air temperature were recorded in degrees Celsius via Davis Vantage VUE (Davis Instruments©; Hayward, CA). A Flow Probe and Global Water Flow Meter (Global Water Instrumentation; College Station, TX) at the front of the flume measured water velocity during the surf simulation.

Meanwhile, baseline core temperature and heart rate were recorded one minute before protocol start time and data collection for all equipment was synchronized with the session's start and end times; these were defined as the moment at which the participant entered and exited the water. Skin temperature data were measured at 1-min intervals along with heart rate and core temperature data using a Polar RCX-5 heart rate watch and a CorTemp Data Recorder v4.3 (9001 Series; HQInc, Palmetto, FL). The protocol sequence and paddling speeds were determined and designed from previous surf research to simulate a typical surf session [5–11].

Participants began by laying on the surfboard, followed by a duck dive, then paddling. The participant then sat on the board, duck dove and paddled again. Each activity was done for 1-min with the exception of the duck-dive which acted as a transition movement and lasted 2 s. The pattern repeated for 60 min with water velocity varying at three consecutive speeds for 20 min each: (1) 1.2 m/s for minutes 1–20, (2) 1.4 m/s for minutes 20–40 and (3) 1.6 m/s for minutes 40–60.

Lastly, a thermal perception scale was introduced to the latter portion of data collection to determine thermal sensation and location during four different time points in males ($n = 10$) and females ($n = 5$) (Appendix IV and V) [29]. The four time points were termed 'Pre' (the first minute of the surf simulation where the participant lay stationary on the surfboard in the water), 'T2' (20-min into protocol before increase in paddle velocity), 'T3' (40-min into protocol before final increase in paddle velocity), 'Post' (at the termination of surf simulation).

Upon completion of the simulated surf protocol skin thermistor data was downloaded using OneWireViewer (Maxim Integrated/Dallas Semiconductor Corp., USA) JavaTM system and transferred into Microsoft Excel for further data analysis along with heart rate, body composition and core temperature data.

2.3 Statistical analysis

All values were reported as mean ± standard deviation (SD). Skin thermistor data were analyzed using a 2 (sex) × 12 (time) RMANOVA at eight thermistor locations to compare three main effects: time, sex and the interaction effect. Studies have concluded significant main effects of skin temperature over time in both male and female surfers, so this was not analyzed [15, 19]. However, to determine the presence of significant sex differences in skin temperature, the main effect of sex and interaction effect of sex × time were analyzed. There were three participants ($n = 2$ males, $n = 1$ female) that experienced a skin thermistor malfunction. All malfunctions and any missing data were not included in the study, but the remaining data were included if not deemed an outlier as determined by Tukey's Boxplot Method of Q1 − (1.5 × IQR) and Q3 − (1.5 × IQR) [35]. All included skin temperature data were then grouped into 12 five-minute epochs, from 0 to 60 min and mean averaged for both sexes. Post hoc comparison for the main effect of sex over time was performed using an independent samples t test setting significance at $\alpha = 0.05$ and a Cohen's d determined effect size. The Benjamini–Hochberg analysis was then applied to each t test at all twelve epochs to control for a false discovery rate [30]. Core temperature and heart rate were also determined using an independent samples t test. Lastly, perceptual data were listed as frequency and no statistical analysis was conducted as sample sizes were too small.

3 Results

3.1 Surf simulation characteristics

During a 60-min surf simulation, there were no significant differences in water and ambient air temperatures or humidity between sexes (Table 2).

3.2 Body composition

For total body fat, males (13.14 ± 3.70%) were leaner than females (18.62 ± 5.84%; $p = 0.014$). More specifically, females had higher fat mass in the arms (1.15 ± 0.50 kg) than males (0.72 ± 0.45 kg; $p = 0.014$; Fig. 1). Leg (females = 3.35 ± 1.09 kg; males = 2.90 ± 0.72 kg, $p = 0.153$; Fig. 1) and trunk fat mass (females = 5.28 ± 2.26 kg; males = 5.00 ± 2.55 kg, $p = 0.750$; Fig. 1) were not significantly different between males and females. Conversely, males exhibited significantly greater skeletal muscle mass than females in the arms (7.54 ± 1.15 kg vs. 4.84 ± 0.98 kg; $p = 0.001$), legs (19.03 ± 2.51 kg vs. 14.27 ± 2.51 kg; $p = 0.001$) and trunk (28.52 ± 3.61 kg vs. 20.31 ± 4.19 kg; $p = 0.001$; Fig. 1).

Table 2 Environmental surf simulation conditions

	Male ($n = 20$)	Female ($n = 13$)	Total ($n = 33$)
Water temp (°C)	16.08 ± 0.33	16.07 ± 0.27	16.08 ± 0.31
Air temp (°C)	20.60 ± 4.85	19.92 ± 2.50	20.33 ± 4.05
Humidity (%)	56.80 ± 16.79	48.62 ± 19.04	53.58 ± 17.88

*Denotes significant differences between sexes at $p < 0.05$. Data expressed as mean ± SD

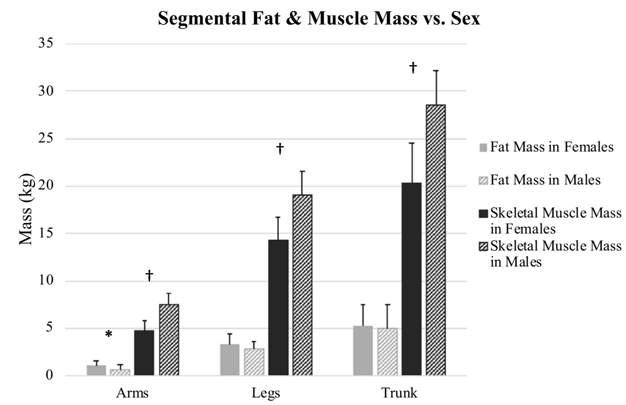

Fig. 1 Segmental fat and skeletal muscle mass differences in the arms, legs and trunk in male and female surfers. *Denotes fat mass significance and †denotes skeletal muscle mass significance, both set at $p < 0.05$ with data expressed as mean ± SD

3.3 Absolute and change in skin temperature

Skin temperature at the beginning of the protocol was significantly lower at the thigh in females (29.90 ± 1.41 °C) than males (30.58 ± 1.10 °C; $p < 0.001$) but not significantly different at the remaining seven anatomical locations between sexes ($p > 0.05$). Given differences in baseline thigh skin temperature between sexes, data were also analyzed as absolute and percent change in skin temperature. An independent samples t test revealed no significant differences in absolute and percent change in skin temperature between sexes at any of the eight anatomical locations ($p > 0.05$; Fig. 2b, c). Additionally, absolute mean skin temperature in males and females at eight anatomical locations during a 60-min surf simulation was analyzed (Fig. 2a). The main effect for sex indicated significantly lower upper arm skin temperatures in females (27.45 ± 1.04 °C) than males (28.61 ± 1.32 °C) at $p < 0.05$, $F = 7.20$, $df = 1$ and significantly lower thigh skin temperatures in females (23.53 ± 0.78 °C) than males (24.73 ± 0.68 °C) at $p < 0.00001$, $F = 21.97$, $df = 1$. However, the main effect of sex for abdomen skin temperatures was significantly lower in males (26.57 ± 1.44 °C) compared to females (27.75 ± 1.50 °C) at $p < 0.05$, $F = 4.87$, $df = 1$. Yet, none of the interactions (sex × time) were significant at any of the eight sensor locations $p > 0.05$.

The main effect for sex revealed significant skin temperature differences at the upper arm, abdomen and thigh. A post hoc analysis of independent samples t test was computed at every epoch for each of the three locations where main effect of skin temperature occurred (Fig. 3). However, after applying the Benjamini–Hochberg analysis to adjust for a false discovery rate, significant skin temperature differences

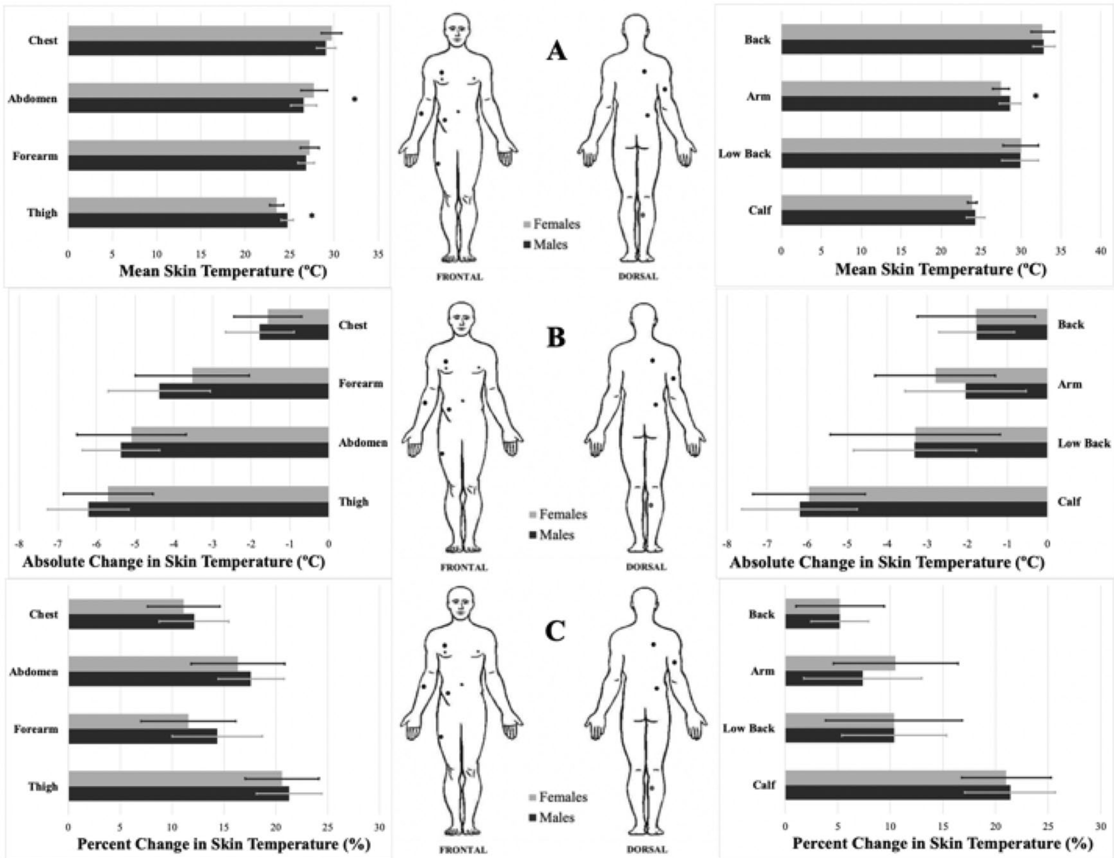

Fig. 2 Absolute mean skin temperatures (**A**), absolute change in skin temperatures (**B**) and percent change in skin temperatures (**C**) between male and female surfers at eight anatomical locations during a 60-min simulated surf session are listed above. *Denotes significance at $p < 0.05$ with data expressed as mean ± SD

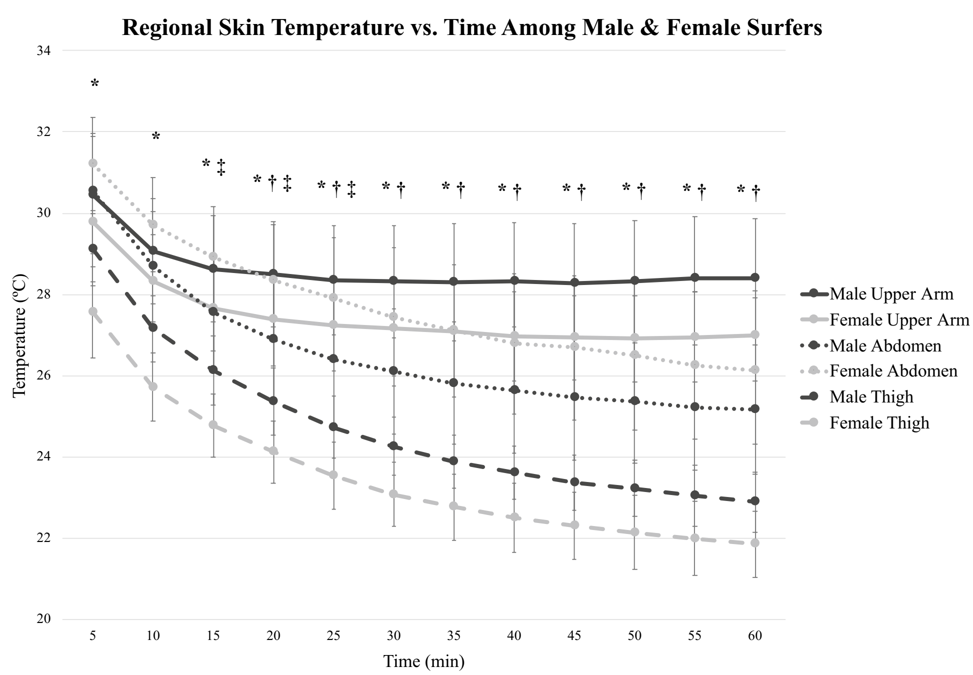

Fig. 3 Surface skin temperature at the upper arm, abdomen and thigh among male and female surfers over a 60-min surf simulation. *Denotes thigh skin temperature significance among sexes, ‡denotes significant differences in abdomen skin temperature among sexes, and †denotes significance in upper arm skin temperature among sexes. Benjamini–Hochberg adjusted α set at $p < 0.0012$, $p < 0.0417$ and $p < 0.0125$ for the thigh, upper arm and abdomen respectively; data expressed as mean ± SD

between sexes only occurred at the thigh across all epochs in addition to the upper arm during all but the first two epochs (Fig. 3, Table 3). Meanwhile, there were only three epochs near the beginning of the protocol where significant sex differences in abdomen skin temperature occurred (Fig. 3, Table 3).

3.4 Absolute change in core temperature

There were no significant differences in absolute core temperature between males (37.31 ± 0.35 °C) and females (37.32 ± 0.48 °C) at $p = 0.99$, $F = 0.00$, $df = 1$.

3.5 Perceptual differences

Nonparametric statistical analysis could not be performed on the perceptual data because of small samples sizes ($n = 10$ males, $n = 5$ females). Additionally, perceived thermal location included general regions of the frontal and dorsal body that were not specific to thermistor location. Therefore, perceptual data could not be correlated to the three locations where significant sex differences in skin temperatures occurred. However, the data still provided insight of perceived thermal sensations during a simulated surf session. Only participants ($n = 6$ males, $n = 4$ females) who perceived thermal sensation at sites where significant sex differences in skin temperature occurred (abdomen, thigh and/or upper arm) were included in the perceptual observations below. Also, only 'Pre' and 'Post' time points were considered to further determine change in thermal perception between sexes during the surf simulation.

Females began the simulation perceiving a below neutral thermal sensation at the abdomen and thigh. Similarly, half of the males began the surf simulation perceiving a below neutral thermal sensation at the abdomen. After sixty minutes of simulated surfing, only one out of the five females reported a thermal sensation while only three out of the six males reported thermal sensations (Table 4). The one female reported the upper arm as 'Slightly Cool' and each of the three males identified thermal sensations at either the upper arm, abdomen or thigh (Table 4). Most remaining males identified post-thermal sensations at the abdomen and thigh as 'Slightly Cool' (Table 4). However, one male reported a 'Neutral' thermal sensation at the upper arm (Table 4). This feedback suggests that by the end of the surf simulation, females may have perceived the upper arm to be slightly cooler than males. Both sexes perceived the abdomen and thigh as cooler locations at the beginning of the protocol. However, by the end of the simulation, the magnitude and scale of thermal perception at these regions no longer existed or appeared to be less impactful.

4 Discussion

The current study elucidated differences in regional skin temperatures at eight anatomical locations in addition to core temperature among male and female surfers during a controlled simulated surf session while wearing a 2-mm wetsuit. Despite two recent field studies, there has been minimal research assessing thermoregulatory responses among surfers in cold water surf conditions and assessing these thermal differences in a controlled environment between sexes [15, 19]. Data in the present study indicated that males and females had similar heat loss patterns across the body during the simulated surf session. However, absolute skin

Table 3 *p* values Cohen's *d* for unpaired *t* tests of sex differences in skin temperature over time ($n = 20$ males, $n = 13$ females, 0–60 min)

	Upper arm		Abdomen		Thigh	
	p value	Cohen's *d*	*p* value	Cohen's *d*	*p* value	Cohen's *d*
Mean Epochs (min)						
5	0.2128	0.4489	0.1745	– 0.5004	0.0001*	1.2519
10	0.1036	0.5812	0.0384	– 0.7475	0.0000*	1.3253
15	0.0314*	0.7562	0.0097*	– 0.9155	0.0001*	1.2817
20	0.0173*	0.8297	0.0104*	– 0.9077	0.0001*	1.2365
25	0.0190*	0.8183	0.0114*	– 0.8977	0.0002*	1.2322
30	0.0196*	0.8152	0.0286	– 0.7870	0.0001*	1.2570
35	0.0164*	0.8357	0.0299	– 0.7813	0.0001*	1.2408
40	0.0071*	0.9265	0.0633	– 0.6753	0.0002*	1.2121
45	0.0072*	0.9254	0.0462	– 0.7216	0.0003*	1.1863
50	0.0063*	0.9392	0.0649	– 0.6713	0.0005*	1.1547
55	0.0053*	0.9553	0.0951	– 0.6101	0.0011*	1.0932
60	0.0055*	0.9526	0.1301	– 0.5557	0.0007*	1.1263

*Denotes comparisons between sexes that were significantly different following Benjamini–Hochberg analysis. A negative Cohen's *d* indicates female temperatures were higher than male temperatures

Table 4 Frequency of 'Pre' and 'Post' thermal sensations at three anatomical locations among male ($n=6$) and female ($n=4$) surfers during a simulated surf session

	Thermal sensation location and scale					
	Upper arm		Abdomen		Thigh	
	Male	Female	Male	Female	Male	Female
Pre						
Slightly warm					1	
Neutral						
Slightly cool	1		1	1	1	1
Cool			2			
Cold				1		
Post						
Slightly warm						
Neutral	1					
Slightly cool		1	1		1	
Cool						
Cold						

temperatures at the upper arm and thigh were significantly colder in females, whereas males were significantly colder at the abdomen. Moreover, there were no significant differences in core temperature between males and females. Altogether, the findings support our first and second hypothesis, that differences in skin temperature exist between sexes at specific anatomical locations, but there are no sex differences in core temperature.

Field studies assessing thermoregulatory responses among surfers suggest females may experience colder surface skin temperatures than males [15, 19]. These sex differences in skin temperature were exhibited at the low back and forearm [15, 19]. However, given the variation in environmental conditions between these field studies, their results must be interpreted with caution. In contrast, the current study demonstrated that under simulated but well-controlled surf conditions, significant sex differences in skin temperatures still occur, with females experiencing colder skin temperatures at the upper arm and thigh rather than previously reported locations of the low back, forearm and abdomen [19]. Additionally, data in the current study suggest males experience colder skin temperatures at the abdomen than females. The sex differences in absolute skin temperatures in the current study may be attributed to increased vasoconstrictive responses in cutaneous circulation and deep limb arterial vessels in females [20, 23]. Previous research suggests that an increase in extremity vasoconstriction would decrease peripheral blood flow and therefore negatively impact surface skin temperatures [20, 23]. Lastly, the current study revealed that thigh skin temperatures in females were significantly colder than males at the start of the surf simulation. This is consistent with previous research that has reported a 0.77–1.00 °C difference in resting thigh skin temperatures between sexes [15, 19, 31, 32].

Meanwhile core temperature and mean heart rate expressed as percentage of workload were not significantly different between sexes. This is comparable to literature that suggests during cold water exposure (20, 24 and 28 °C), males and females exercising at the same workloads yield similar thermoregulatory responses [33]. Therefore, variances in body composition may also explain differences in skin temperatures exhibited between sexes. Similar to previous literature, males in the current study had significantly greater skeletal muscle mass in the arms, legs and trunk than females, while females had significantly greater adiposity in the arms and a non-significant trend to increased adiposity in the legs and trunk than males [34]. Body fat provides greater thermal resistance than skin or wet muscle tissue and acts to insulate core temperature by interfering in heat transfer between body and environment when exposed to cold environmental conditions [4, 12, 23, 24, 33, 35, 36]. Therefore, regions of the body with increased adiposity will experience greater insulation from favorable subcutaneous fat distribution over the active musculature and because circulation remains below the level of fat, it minimizes conductive heat transfer to the skin resulting in decreased surface skin temperatures [4, 33]. This trend was evident in the current study with females exhibiting greater adiposity and colder skin temperatures at the upper arm and thigh than males.

Perceptually, research suggests females may be more thermally sensitive to the environment compared to males [37]. Additionally, in the current study, the difference in change in absolute skin temperature between sexes at the upper arm, abdomen and thigh (− 0.76, − 0.28 and − 0.51 Δ °C respectively) albeit small, exceeded previously reported thermal sensation thresholds [38]. This would suggest variances in perceived thermal sensation may exist between sexes at these locations. Perceptual data in the current study are in alignment with this at the upper arm in females and the abdomen in males but not in alignment at the thigh. Rather, males perceived the thigh as a colder location, yet skin temperatures were significantly colder in females. Although the perceptual data from the current study offer insight, it should be taken with caution and is purely speculative as no statistical analyses were computed due to study limitations. Moreover, it is important to note that the sample size in the current study was small and is therefore a limitation. Thus, all data and results comparing sex differences in skin and core temperature, body composition and perception should be interpreted with caution and may not apply to the entire population.

5 Conclusion

The findings demonstrate that absolute regional skin temperatures vary between male and female recreational surfers under controlled environmental conditions. However, these differences may be too small to translate into perceptual differences and therefore may be unnecessary when considering apparel and wetsuit design. While there were variances in regional skin temperature between sexes at the upper arm, abdomen and thigh, they were under 1 °C and when data were presented in absolute and percent change in skin temperature, they disappeared altogether. Additionally, since no statistical analyses were computed on the perceptual data, it becomes challenging to discern if either sex had greater cold perception at regions where significant skin temperature differences existed. Moreover, there were no differences in core temperature or heart rate expressed as workload. Therefore, the findings suggest that future wetsuit design may not need to consider thermoregulatory sex differences and the current distribution of neoprene thickness can still be applied to both sexes.

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Code availability Not applicable.

Declarations

Conflict of interest Not applicable.

Ethical approval All procedures were approved by the Institutional Review Board at California State University, San Marcos (#1302166).

Consent to participate All prospective participants provided their informed consent before participation.

Consent for publication All authors have approved the submission of this manuscript.

References

1. Moran K, Webber J (2013) Surfing injuries requiring first aid in New Zealand, 2007–2012. Int J Aquat Res Educ 7:192–203
2. Nimmo M (2004) Exercise in the cold. J Sports Sci 22(10):898–916. https://doi.org/10.1080/0264041400005883
3. Naebe M, Robins N, Wang X, Collins P (2013) Assessment of performance properties of wetsuits. Proc Inst Mech Eng Part P J Sports Eng Technol 227(4):255–264. https://doi.org/10.1177/1754337113481967
4. Pandolf K, Sawka M (1988) Human performance physiology and environmental medicine at terrestrial extremes. Cooper Publishing Group, Richard
5. Bravo M, Cummins M, Nessler A, Newcomer C (2016) Heart rate responses of high school students participating in surfing physical education. J Strength Cond Res 30(6):1721–1726. https://doi.org/10.1519/JSC.0000000000001263
6. Farley RL, Harris K, Kilding E (2012) Physiological demands of competitive surfing. J Strength Cond Res 26(7):1887–1896. https://doi.org/10.1519/JSC.0b013e3182392c4b
7. Farley RL, Secomb L, Raymond R, Lundgren E, Ferrier K, Abbiss R, Sheppard M (2018) Workloads of competitive surfing: work-to-relief ratios, surf-break demands, and updated analysis. J Strength Cond Res 32(10):2939–2948. https://doi.org/10.1519/JSC.0000000000002659
8. Meir RA, Lowdon BJ, Davie AJ (1991) Heart rates and estimated energy expenditure during recreational surfing. Aust J Sci Med Sport 23:70–74
9. Mendez-Villanueva A, Bishop D (2005) Physiological aspects of surfboard riding performance. Sports Med 35(1):55–70. https://doi.org/10.2165/00007256-200535010-00005
10. Mendez-Villanueva A, Bishop D, Hamer P (2006) Activity profile of world-class professional surfers during competition: a case study. J Strength Cond Res 20(3):477–482. https://doi.org/10.1519/16574
11. Secomb JL, Sheppard JM, Dascombe BJ (2015) Time-motion analysis of a 2-hour surfing training session. Int J Sports Physiol Perform 10(1):17–22. https://doi.org/10.1123/ijspp.2014-0002
12. Prisby RD, Glickman-Weiss EL, Caine N (2000) Thermal sensation and substrate utilization differs among low- and high-fat women exposed to 17 °C water. Wilderness Environ Med 11(3):157–162. https://doi.org/10.1580/1080-6032(2000)011[0157:TSASUD]2.3.CO;2
13. Wakabayashi H, Hanai A, Yokoyama S, Nomura T (2006) Thermal insulation and body temperature wearing a thermal swimsuit during water immersion. J Physiol Anthropol 25(5):331–338. https://doi.org/10.2114/jpa2.25.331
14. Wakabayashi H, Kaneda K, Sato D, Tochihara Y, Nomura T (2008) Effect of non-uniform skin temperature on thermoregulatory response during water immersion. Eur J Appl Physiol 104(2):175–181. https://doi.org/10.1007/s00421-008-0714-x
15. Corona LJ, Simmons GH, Nessler JA, Newcomer SC (2018) Characterisation of regional skin temperatures in recreational surfers

wearing a 2-Mm wetsuit. Ergonomics 61(5):729–735. https://doi.org/10.1080/00140139.2017.1387291
16. Bergh U, Ekblom B (1979) Influence of muscle temperature on maximal muscle strength and power output in human skeletal muscles. Acta Physiol Scand 107(1):33–37. https://doi.org/10.1111/j.1748-1716.1979.tb06439.x
17. Oksa J, Rintamäki H, Rissanen S (1997) Muscle performance and electromyogram activity of the lower leg muscles with different levels of cold exposure. Eur J Appl Physiol Occup Physiol 75(6):484–490. https://doi.org/10.1007/s004210050193
18. Sargeant AJ (1987) Effect of muscle temperature on leg extension force and short-term power output in humans. Eur J Appl Physiol Occup Physiol 56(6):693–698. https://doi.org/10.1007/BF00424812
19. Warner ME, Nessler JA, Newcomer SC (2019) Skin temperatures in females wearing a 2 Mm wetsuit during surfing. Sports 7(6):145. https://doi.org/10.3390/sports7060145
20. Bollinger A, Schlumpf M (1976) Finger blood flow in healthy subjects of different age and sex and in patients with primary Raynaud's disease. Acta Chir Scand Suppl 465:42–47 ((**PMID: 1069432**))
21. Charkoudian N (2003) Skin blood flow in adult human thermoregulation: how it works, when it does not, and why. Mayo Clin Proc 78(5):603–612. https://doi.org/10.4065/78.5.603
22. Graham TE (1988) Thermal, metabolic, and cardiovascular changes in men and women during cold stress. Med Sci Sports Exerc 20(5 Suppl):S185–S192
23. Keatinge WR (1960) The effects of subcutaneous fat and of previous exposure to cold on the body temperature, peripheral blood flow and metabolic rate of men in cold water. J Physiol 153(1):166–178
24. Salamunes ACC, Stadnik AMW, Neves EB (2017) The effect of body fat percentage and body fat distribution on skin surface temperature with infrared thermography. J Therm Biol 66:1–9. https://doi.org/10.1016/j.jtherbio.2017.03.006
25. Tukey JW (1977) Exploratory data analysis. Addison-Wesely, Boston
26. Leeworthy VR, Wiley PC (2001) Current participation patterns in marine recreation. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Special Projects, pp 20–21
27. Esco MR, Snarr RL, Leatherwood MD et al (2015) Comparison of total and segmental body composition using DXA and multifrequency bioimpedance in collegiate female athletes. J Strength Cond Res 29:918–925
28. Schubert MM, Seay RF, Spain KK, Clarke HE, Taylor JK (2019) Relaiability and vailidity of various laboratory methods of body composition assessment in young adults. Clin Physiol Funct Imaging 39(2):150–159
29. Raccuglia M, Heyde C, Lloyd A, Ruiz D, Hodder S, Havenith G (2018) Anchoring biases affect repeated scores of thermal, moisture, tactile and comfort sensations in transient conditions. Int J Biometeorol 62(11):1945–1954. https://doi.org/10.1007/s00484-018-1595-2
30. Benjamini Y, Hochberg Y (1995) Controlling the false discovery rate: a practical and powerful approach to multiple testing. J R Stat Soc Ser B (Methodol) 57(1):289–300. https://doi.org/10.1111/j.2517-6161.1995.tb02031.x
31. Chudecka M, Lubkowska A (2015) Thermal maps of young women and men. Infrared Phys Technol 69:81–87. https://doi.org/10.1016/j.infrared.2015.01.012
32. Marins JCB, Formenti D, Costa CMA, Alex de Andrade A, Sillero-Quintana M (2015) Circadian and gender differences in skin temperature in militaries by thermography. Infrared Phys Technol 71:322–328. https://doi.org/10.1016/j.infrared.2015.05.008
33. McArdle WD, Magel JR, Gergley TJ, Spina RJ, Toner MM (1984) Thermal adjustment to cold-water exposure in resting men and women. J Appl Physiol 56(6):1565–1571. https://doi.org/10.1152/jappl.1984.56.6.1565
34. John BM, Joshua R, Oliver R, Mark D, John O (2016) Anthropometric and performance perspectives of female competitive surfing. Hum Mov 17(3):154–161. https://doi.org/10.1515/humo-2016-0023
35. Buskirk ER, Thompson RH, Donald Whedon G (1963) Metabolic response to cold air in men and women in relation to total body fat content. J Appl Physiol 18(3):603–612. https://doi.org/10.1152/jappl.1963.18.3.603
36. Neves EB, Moreira TR, Lemos RJ, Vilaça-Alves J, Rosa C, Reis VM, Neves EB et al (2015) The influence of subcutaneous fat in the skin temperature variation rate during exercise. Res Biomed Eng 31(4):307–312. https://doi.org/10.1590/2446-4740.0805
37. Parsons KC (2002) The effects of gender, acclimation state, the opportunity to adjust clothing and physical disability on requirements for thermal comfort. Energy Build Spec Issue Therm Comf Stand 34(6):593–599. https://doi.org/10.1016/S0378-7788(02)00009-9
38. Choo J, Stevens C, Kenneth K (1998) Temperature sensitivity of the body surface over the life span. Somatosens Motor Res 15(1):13–28. https://doi.org/10.1080/08990229870925