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# The characterization of thermal perception in recreational surfers wearing wetsuits

Mackenzie Warner [a], Jeff A. Nessler [a,*], Davide Filingeri [b], Sean C. Newcomer [a]

[a] Dept of Kinesiology, California State University, San Marcos, CA, 92096, USA
[b] ThermosenseLab, Skin Sensing Research Group, School of Health Sciences, University of Southampton, Southampton, UK

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ABSTRACT

The purpose of this study was to characterize the perception of heat loss, comfort, and wetness in recreational surfers wearing wetsuits, to compare these data with changes in skin temperature reported in prior studies, and to examine the impact of wetsuit thickness, zipper location, and accessory use on thermal sensation and comfort. Following their surf session, nine-hundred and three male (n = 735) and female (n = 168) recreational surfers responded to a series of questions regarding thermal comfort/sensation, wetsuit characteristics, and surfing history. Average whole body thermal sensation rating was 0.8 ± 3.6 on a scale of −10 to +10 and average whole body thermal comfort rating was 1.5 ± 1.2, midway between "just comfortable" and "comfortable." Overall, surfers felt coldest in their feet, hands, and head. Under their wetsuits, surfers felt the coldest, wettest, and least comfortable in their chest, lower legs, lower arms, and upper back. Wetsuit accessory use had the greatest impact on regions identified as coldest, least comfortable, and wettest. These data suggest that wetsuit design should focus on optimizing water access points and improving accessories for the feet, hands, and head.

## 1. Introduction

Surfing is a global sport with over 37 million participants worldwide (Loveless and Minahan, 2010; Meir et al., 1991; Moran and Webber, 2013). Surfers often go to great lengths to find perfect or uncrowded waves and are frequently exposed to harsh environments with cold water and air temperatures. Surfers utilize wetsuits, which are primarily made from polychloroprene closed cell foam, as a thermal barrier between the skin and the environment to protect them from cold water and air exposure. The hydrophobic and insulating properties of polychloroprene help reduce convective heat loss and allow surfers to maintain normothermia during a surf session (Naebe et al., 2013). Additionally, wetsuits allow small amounts of water to pass through the suit from entry points or seams, creating a thin layer of warm water between the neoprene and skin, further aiding the thermoregulatory process (Naebe et al., 2013). However, while wetsuits can help to mitigate the effects of cold water and air, heat loss still occurs during a typical surf session (Corona et al., 2018; Naebe et al., 2013; Warner et al., 2019).

Regional heat losses, as measured by changes in skin temperature, are unevenly distributed across the body in recreational surfers wearing wetsuits (Corona et al., 2018; Skillern et al., 2021; Warner et al., 2019). The greatest amount of heat loss during surfing was reported to occur in the lower legs (≈−6.0 °C), thighs (≈−4.5 °C), and lower abdomen (≈−5.0 °C) (Corona et al., 2018; Skillern et al., 2021; Warner et al., 2019). These temperature differences are likely due to variations in submersion and interaction with water since surfing involves a unique combination of movement and physical activity. For example, the greatest proportion of time during a typical surf session is spent paddling (47%), in which the body is partially submerged and the arms are intermittently submerged. In addition, surfers spend 38% of their time stationary, often sitting on their boards, and another 10% of time in miscellaneous activity, which includes full submersion during activities such as duck-diving and swimming. During wave riding, the body remains completely above the water, but this activity accounts for only 6% of time spent surfing (Bravo et al., 2016; Farley et al., 2012, 2018; Meir et al., 1991; Mendez-Villanueva et al., 2006; Mendez-Villanueva and Bishop, 2005; Secomb et al., 2015). This pattern of activity and submersion, combined with the many different environmental variables that a surfer might encounter, presents a difficult challenge for the design of a high performing wetsuit.

The perception of thermal comfort and sensation while surfing are

* Corresponding author. Dept. of Kinesiology California State University, San Marcos 333 S. Twin Oaks Valley Rd. San Marcos, CA, 92096, USA.
*E-mail address:* jnessler@csusm.edu (J.A. Nessler).

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also important factors to consider. An individual's perception of thermal sensation is influenced by several factors including exercise (Filingeri et al., 2018; Gerrett et al., 2014; Gerrett et al., 1522), age (House and Tipton, 2015; Stevens and Choo, 1998), sex (Gerrett et al., 2014; Gerrett et al., 1522), and internal (core) temperature (Attia and Engel, 1982; Chatonnet and Cabanac, 1965). Thermal sensations also vary across anatomical locations (Filingeri et al., 2014, 2018; Stevens and Choo, 1998), which is particularly relevant for wetsuit design. Further, thermal sensation is associated with the perception of skin wetness (Filingeri et al., 2014; Filingeri and Havenith, 2015; Valenza et al., 2019), which may have implications for surfers' thermal comfort. Currently there are limited data available on thermal perception in aquatic athletes, particularly those who are exercising or wearing a wetsuit. One study reported that wearing a wetsuit improved thermal comfort in swimmers (Rois et al., 2021), but other studies have found that minor alterations in wetsuit design (Denny et al., 2022; Paterson et al.; Smith et al., 2020) and differences between sexes (Skillern et al., 2021) had little impact on a surfer's perception of thermal sensation while wearing a wetsuit. However, the results of these studies should be interpreted with caution given their relatively small sample sizes (Rois et al., 2021; Skillern et al., 2021; Smith et al., 2020).

There are currently no studies that provide insight into how closely thermal sensation and comfort of surfers wearing wetsuits align with previously published data on skin temperature changes that occur during surfing. Further, there are no studies that investigate the relationship between properties of wetsuits and thermal sensation and comfort of the surfing athlete. Therefore, the purpose of this study was threefold. The first purpose was to characterize the perception of heat loss, comfort, and sensation in surfers while wearing a wetsuit and engaged in recreational surfing. The second purpose was to compare these perceptual data with previously reported skin temperature data for recreational surfers. The third purpose was to examine the relationship between wetsuit thickness, type of wetsuit entry (back zip, chest zip, and zipperless), and accessory use (booties, hood, and gloves) vs thermal sensation and comfort. We hypothesized that perception of heat loss, comfort, and wetness would closely align with previously reported skin temperature data during recreational surfing in a wetsuit (Corona et al., 2018; Warner et al., 2019). We further hypothesized that thermal sensation and comfort would be strongly associated with wetsuit thickness, entry, and use of accessories.

## 2. Materials and methods

### 2.1. Participants

A total of nine-hundred and three male (n = 735) and female (n = 168) recreational surfers were recruited from beaches in Northern, Central, and Southern California for this study. All participants had at least 1 year of prior surfing experience, were between the ages of eighteen and eighty years of age, and were wearing a full wetsuit. Surfers wearing anything other than a full wetsuit (e.g. spring suit, short arm full, no wetsuit) were excluded from the study. Participant characteristics are reported in Table 1. All participants were informed of the benefits and risks of the study prior to participation. All procedures were approved by the Institutional Review Board at California State University San Marcos (IRB# 1645611).

### 2.2. Study design

Potential participants were approached and recruited on the beach prior to entering the water for their surf session. Participants were informed that upon returning to the beach they would be asked a series of questions regarding their perceived thermal comfort and sensation, wetsuit characteristics, surfing history, and anthropometric data. Prior to conducting the survey, the researchers informed the participants that if they felt uncomfortable answering any question(s) during the post-surf questionnaire they could stop at any time. Participants then completed their surf session as normal, with no restrictions on duration, in their personal wetsuit. The surf session began when each participant entered the water and ended when they exited the water and total time spent surfing was recorded (reported in Table 1 as "Session Duration"). Water temperature, swell height, and swell direction were obtained from the National Oceanic and Atmospheric Administration's offshore buoys (surfline.com). Ambient air temperature, cloud coverage (%), wind speed, and wind direction, were obtained from the National Weather Service (accuweather.com).

**Table 1**
Participant characteristics.

| | Totals | Males | Females |
|---|---|---|---|
| | *n = 903* | *n = 733* | *n = 168* |
| **Age (years)** | 38 ± 12 | 39 ± 13 | 35 ± 9 |
| **Height (cm)** | 178 ± 9 | 180 ± 7 | 167 ± 7 |
| **Mass (kg)** | 76 ± 12 | 79 ± 10 | 60 ± 8 |
| **Years surfing** | 17 ± 13 | 19 ± 13 | 8 ± 8 |
| **Hours/week surfing** | 6 ± 5 | 6 ± 4 | 6 ± 5 |
| **Board length (cm)[a]** | 225 ± 44 | 222 ± 45 | 237 ± 41 |
| **Perceived Exertion[a]** | 10.9 ± 2.3 | 10.9 ± 2.3 | 10.9 ± 2.2 |
| **Session Duration (min)[a]** | 83.5 ± 34.8 | 83.6 ± 35.1 | 83.1 ± 33.5 |

Data are mean ± SD.
[a] These data refer to the specific session at which the participants were surveyed.

### 2.3. Post surf questionnaire

Upon returning to the beach from their surf session, participants were asked a series of questions regarding their perceived exertion, whole body thermal comfort and sensations, regional thermal comfort and sensations, wetsuit characteristics, surfing experience, and anthropometric data. First, participants were shown a diagram of the Borg Rating of Perceived Exertion Scale (RPE) and asked to pick a number on the scale (from 6 to 20) that they deemed appropriate based on their perceived exertion during their surf session (Borg, 1982) (reported in Table 1 as "Perceived Exertion"). Next, a thermal sensation scale, ranging from −10 to 10 (−10: very cold, 0: neutral, +10: hot) was shown to the participants and they were asked to pick the number that best corresponded to how their whole body felt during their surf session (note: only scores of integers were allowed, scale modified from: (Filingeri et al., 2018; Gerrett et al., 1522). Participants were then shown a thermal comfort scale and were asked to rate their whole-body thermal comfort level based on the choices of very uncomfortable, uncomfortable, just uncomfortable, just comfortable, comfortable, and very comfortable (Bird et al., 2015). This was later coded to a numerical scale (3 Very comfortable to −3 Very uncomfortable) for data analysis.

The next series of questions pertained to regional thermal comfort and sensations. First, participants were asked to identify what body region, only covered by their wetsuit, felt the coldest, wettest, and most thermally uncomfortable during their surf sessions (Olesen and Brager, 2004). Regions underneath the wetsuit included the upper arms, axilla, lower arms, chest, abdomen, upper back, lower back, genitalia, upper legs, and lower legs. The head, hands, and feet were excluded as options for this question. In addition, wetsuit accessories including booties, gloves, and hoods were not considered to be part of the full wetsuit. Participants were then asked to choose what body region beneath their wetsuit they wished was warmer, drier, and more thermally comfortable. Participants were rated as "indiscriminate" if they could not tell where they felt coldest/most uncomfortable/wettest and declined to identify a single region. In addition, participants who stated that they did not feel cold under their wetsuit were included in this category. Participants were then asked the same series of six questions regarding regional thermal comfort and sensations, referring to their whole body, covered or uncovered by the wetsuit (including the head, hands, or feet) or any wetsuit accessories.

After the whole body and localized thermal comfort and sensation questions, participants were asked questions concerning their wetsuit characteristics. These included their wetsuit brand, model, color, mode of entry (chest zip, back zip, or zipperless), thickness, size, age of wetsuit, or areas of leakage (holes, rips, or seam splits). Researchers also noted if the participant was wearing wetsuit accessories such as a hood, gloves, and/or booties. Next, participants were asked about their surfing details including their surfboard length, years of surfing experience, and average hours per week surfed. Participant hometown and years lived in their respective geographical region (Northern, Central, or Southern California) were also noted. Finally, participants were asked anthropometrical questions, including their age, sex, estimated height and mass, and ethnicity.

### 2.4. Data management and analysis

Microsoft Forms was used to conduct all survey data and collect participant responses. After data collection, responses were downloaded to Microsoft Excel for data analysis. Frequency distributions were performed on all twelve regional thermal comfort and sensation questions, which referred to regions underneath the wetsuit and across the whole body. All descriptive statistics are reported as mean ± standard deviation (with the exception of data from prior studies). To simplify data analysis, wetsuit thickness was grouped into four categories (2 mm, 3 mm, 4 mm, 5 mm) based upon the thickness of neoprene at the trunk. For example a 3/2 mm wetsuit was grouped into the 3 mm category. It should be noted that there can be considerable variability in neoprene thickness across regions of a typical wetsuit, both by design (i.e. 4/3/2 mm wetsuit) and by manufacturing tolerances. Therefore, these simplified categories potentially encompass a broad range of thicknesses.

Multinomial logistic regression was used to examine the relationship between wetsuit properties (thickness, entry, and accessory use) and the participants' ratings of thermal comfort, thermal sensation, and their coldest, most uncomfortable, and wettest regions over their whole body. Fifteen separate regression models were evaluated – one for each wetsuit property and each type of participant rating (3 properties x 5 different ratings). Each individual regression model consisted of three factors: one wetsuit property and two environmental variables, and one predicted outcome variable: either thermal comfort, sensation, or region that was coldest, most uncomfortable, or wettest. Water and air temperature were included in each regression model as covariates to account for the impact of environmental conditions. The reference conditions for each regression model were as follows: thermal comfort (2: comfortable), thermal sensation (0: neutral), coldest region (feet – most common response), most uncomfortable region (feet – most common response), wettest (head/neck – most common response). To avoid the effects of multicollinearity and to facilitate direct comparison among wetsuit categories, the intercept was removed from each regression model. Any significant result ($p < 0.05$) for wetsuit factor was noted and the odds ratio (Exp(B)) was recorded for that case.

## 3. Results

### 3.1. Surf activity profile, wetsuit characteristics, and environmental conditions

Participant (n = 903) surf sessions ranged from 10 to 300 min with a mean session duration of 83 ± 35 min (Table 1). The mean wetsuit age was 2 ± 2 years old, and three different types of wetsuit entry designs were recorded: chest zips (n = 602), back zips (n = 216), and zipperless (n = 85). Wetsuit thicknesses were comprised of 5 mm (including 5/4 mm and 5/4/3 mm, n = 58), 4 mm (including 4/3 mm, 4/3/2 mm, n = 372), 3 mm (including 3/2 mm, n = 460), and 2 mm (n = 13). Forty-two different wetsuit brands were documented in this study. Ocean water temperature ranged from 11° to 22 °C, with a mean water temperature of 16.4 ± 2.5 °C. Mean swell height, swell interval, and swell direction were 0.8 ± 0.5 m, 13 ± 3 s, and 237 ± 37°, respectively. Air temperature ranged from 3° to 30.0 °C with a mean air temperature of 17° ± 5.5 °C. Wind speed ranged from 0 to 20 km/h with a mean wind speed of 7 ± 4.20 km/h. Mean wind direction was 188 ± 99°. Mean humidity and cloud coverage were 69 ± 25% and 53 ± 45%, respectively (Table 2). Several differences were noted in survey results from the three different geographical regions and are presented in Table 3.

### 3.2. Whole body thermal comfort and sensations

Reported RPE of participants' surf sessions ranged from 6 to 19 with an average reported RPE of 11 ± 2 (Table 1). Reported whole body thermal sensation rating ranged from −9 to 10 with an average whole body thermal sensation rating of 0.8 ± 4 on a scale of −10 to 10 (Fig. 1). Whole body thermal sensation exhibited a weak correlation with water and air temperature ($p < 0.001$, $r = 0.166$ & 0.173, respectively). Reported whole body thermal comfort rating ranged from −3 (very uncomfortable) to 3 (very comfortable) with an average whole body thermal comfort rating of 1.5 ± 1.2, which corresponded to halfway between "just comfortable" and "comfortable" on the thermal comfort rating scale (Fig. 1). Whole body thermal comfort also exhibited a weak correlation with water and air temperature ($p < 0.001$, $r = 0.110$ & 0.136, respectively). Shapiro-Wilk test indicated that neither thermal sensation or comfort exhibited a normal distribution ($p < 0.001$); thermal sensation was platykurtic (kurtosis = −0.1) and thermal comfort was skewed toward the comfortable rating (skewness = −1.2) as there was no neutral value to this scale.

### 3.3. Anatomical differences in thermal comfort and sensations underneath the wetsuit

Results for anatomical differences in perceived thermal comfort and sensations are reported as the frequency (%) that each body region was selected by the surfer (Table 4, Fig. 2). The most frequently reported coldest regions under the wetsuit were the chest (15.4%), lower legs/calves (14.8%), lower arms/forearms (11.7%), and upper back (8.6%). Furthermore, 22.9% of the participants were labeled as non-responders because they either (Attia and Engel, 1982) could not tell where they were cold under their wetsuit, or (Bennett, 1984) they reported not being cold under their wetsuit (Table 4). The most frequently reported regions under the wetsuit where surfers wanted to be warmer were the chest (18.5%) and lower legs (11.5%) with the remaining regions reported 8% or less of the time. The most frequently reported thermally uncomfortable regions under the wetsuit were the chest (20.6%), upper back (11.3%), lower legs (9.3%), and lower arms (7.1%). The most frequently reported region under the wetsuit where surfers wanted to be more thermally comfortable was the chest (22.4%). The remaining regions were reported less than 10% of the time. The most frequently reported wettest regions under the wetsuit were the chest (16.9%), upper back (9.2%), lower back (8.2%), and lower arms (6.8%). The most

**Table 2**
Environmental conditions.

| | Mean +SD | Minimum | Maximum |
|---|---|---|---|
| **Water Temperature (°C)** | 16.4 ± 2.5 | 11 | 22 |
| **Swell Height (m)** | 0.8 ± 0.5 | 0.3 | 2.5 |
| **Swell Interval (s)** | 13 ± 3 | - | - |
| **Swell Direction (deg.)** | 237 ± 37 | - | - |
| **Air Temperature (°C)** | 17 ± 5.5 | 3 | 30.0 |
| **Wind Speed (km/h)** | 7 ± 4.20 | 0 | 20 |
| **Wind Direction (deg.)** | 188 ± 99 | - | - |
| **Humidity (%)** | 69 ± 25 | 13 | 99 |
| **Cloud coverage (%)** | 53 ± 45 | 0 | 100 |

Data are mean ± SD.

**Table 3**
Differences among geographical regions surveyed.

| | Southern California | Central California | Northern California |
|---|---|---|---|
| **Surfers Surveyed** | 715 | 56 | 131 |
| **Water Temperature (°C)** | 17.5 ± 1.4 | 12.1 ± 0.3 | 12.1 ± 0.3 |
| **Air Temperature (°C)** | 18.2 ± 4.7 | 9.1 ± 4.8 | 12.3 ± 4.3 |
| **Cloud Coverage (%)** | 60.1 ± 44.8 | 19.9 ± 25.1 | 29.1 ± 36.3 |
| **Wind Speed (km/hr)** | 6.9 ± 4.3 | 8.9 ± 5.9 | 6.9 ± 2.8 |
| **Humidity (%)** | 70.9 ± 25.9 | 59.9 ± 18.4 | 59.9 ± 18.9 |
| **Surfer Age (years)** | 39.3 ± 12.5 | 36 ± 9.2 | 38.4 ± 11.1 |
| **Accessory Use** | Booties: 9% Any: 12% | Booties: 68% Any: 82% | Booties: 82% Any: 87% |
| **Wetsuit Thickness** | 2 mm: 1% 3 mm: 56% 4 mm: 42% 5 mm: 1% | 2 mm: 0% 3 mm: 7% 4 mm: 74% 5 mm: 20% | 2 mm: 0% 3 mm: 6% 4 mm: 55% 5 mm: 40% |

Data: mean ± SD.

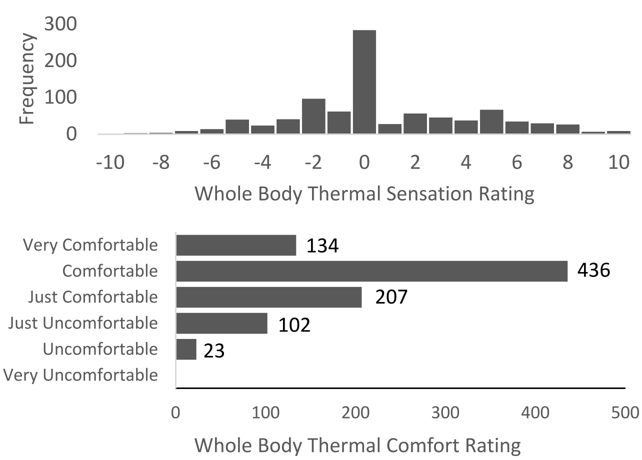


**Fig. 1.** Frequency distribution of recreational surfers' (n = 903) perceived whole body thermal sensation (top) and comfort (bottom) ratings during an average surf session.

frequently reported region under the wetsuit where surfers wanted to be drier was the chest (20.2%). The remaining regions were reported less than 10% of the time (Table 4, Fig. 2).

### 3.4. *Anatomical differences in thermal comfort and sensations on the whole body*

The regions most frequently reported as coldest on the whole body were the feet (45.8%), hands (31.0%), head (11.4%), and chest (2.8%, Fig. 3). Only 2% of participants were labeled 'non-responders.' Surfers most frequently reported wanting to be warmer in their feet (29.6%), hands (18.3%), chest (10.9%), and head (9.3%). The most frequently reported thermally uncomfortable regions on the whole body were the feet (34.3%), hands (24.3%), head (10.3%), and chest (5.5%). Surfers reported wanting to be more thermally comfortable in the feet (24.5%), hands (15.8%), chest (11.4%), and head (9.6%). The most frequently reported wettest regions on the whole body were the head (30.3%), feet (27.1%), hands (9.4%), and lower legs (7.3%). Surfers most frequently reported wanting to be drier on their whole body on their heads (19.3%), chest (10.2%), feet (9.1%), and lower legs (6.1%).

**Table 4**
Changes in skin temperatures reported in prior studies (°C) compared with regions perceived by surfers to be coldest under their wetsuit in the current study.

| | Skin Temperature Changes Reported in Prior Studies (°C) | | Regions Rated Coldest Under Wetsuit | | |
|---|---|---|---|---|---|
| | Males (n = 46)[a] | Females (n = 27)[b] | Males (n = 733) | Females (n = 168) | Total (n = 903) |
| **Chest** | −1.98 ± 0.31 | −2.27 ± 0.49 | 15.3% | 16.1% | 15.4% |
| **Forearm** | −2.93 ± 0.23 | −4.26 ± 0.30 | 11.3% | 13.7% | 11.7% |
| **Abdomen** | −4.88 ± 0.29 | −5.47 ± 0.32 | 2.9% | 4.2% | 3.1% |
| **Thigh** | −4.55 ± 0.28 | −4.61 ± 1.54 | 5.1% | 3.0% | 4.7% |
| **Upper back** | −1.58 ± 0.28 | −1.15 ± 0.37 | 9.4% | 5.4% | 8.6% |
| **Upper arm** | −2.08 ± 0.3 | −1.95 ± 0.44 | 3.7% | 8.3% | 4.5% |
| **Lower back** | −3.56 ± 0.38 | −5.03 ± 0.45 | 7.5% | 8.9% | 7.9% |
| **Calf** | −5.50 ± 0.23 | −5.56 ± 0.30 | 15.4% | 12.5% | 14.8% |
| **Did Not Feel Cold** | | | 16.0% | 14.9% | 15.7% |
| **Indiscriminate** | | | 6.7% | 8.9% | 7.2% |

Data are mean ± SEM.
[a] Corona et al., 2018.
[b] Warner et al., 2019.

### 3.5. *Impact of wetsuit characteristics on thermal comfort and sensation*

There was a significant negative correlation between wetsuit thickness and water temperature ($r = -0.519$, $p < 0.001$). Multinomial logistic regression indicated that wetsuit thickness had a significant impact on where surfers felt coldest or most uncomfortable over their entire body when the variables of water temperature and air temperature were held at a fixed value. Surfers who wore a 3 mm or 4 mm were significantly less likely to report that they were cold in the upper arms ($p = 0.022$ & 0.023, OR<0.001 for both), lower legs ($p = 0.037$ & 0.026, OR<0.001 for both), lower back ($p = 0.015$ & 0.010, OR<0.001 for both), or chest ($p = 0.023$ & 0.047, OR = 0.012 & 0.045, respectively) compared with their feet. Surfers wearing a thicker wetsuit (3 mm, 4 mm, 5 mm) were also more likely to report that their hands were colder compared to their feet ($p < 0.001$ for all, OR = 18.4, 20.6, 20.6, respectively). This result may reflect an interaction between wetsuit thickness and accessory use, as a higher percentage of surfers who wore thicker wetsuits also wore booties (Table 5).

Wetsuit thickness also impacted where surfers felt most uncomfortable. Surfers with thicker wetsuits were less likely to report feeling uncomfortable at the abdomen ($p = 0.005$, 0.006, 0.008, OR<0.001 for 3 mm, 4 mm, 5 mm respectively), chest ($p = 0.001$, OR = 0.006, 0.007, 0.010 for 3 mm,4 mm, 5 mm respectively), lower back ($p = 0.002$, 0.003, 0.003, OR<0.001 for 3 mm, 4 mm, 5 mm respectively), lower legs ($p = 0.006$ & 0.003, OR = 0.001 for 3 mm, 4 mm respectively), upper legs ($p = 0.035$ & 0.039, OR<0.001 for 3 mm, 4 mm respectively), upper arms ($p = 0.011$, 0.013, 0.016, OR = 0.006, 0.010, 0.010 for 3 mm, 4 mm, 5 mm respectively), and upper back ($p = 0.004$, OR = 0.002 & 0.003 for 3 mm, 4 mm respectively) compared with the feet. Surfers who wore thicker wetsuits were also more likely to report that they felt uncomfortable at the hands ($p = 0.042$, 0.004, 0.002, OR = 4.45, 6.59. 6.61 for 3 mm, 4 mm, 5 mm respectively) and head/neck ($p = 0.045$ & 0.048, OR = 6.94 & 5.32 for 3 mm, 4 mm respectively) compared with the feet. The regression model also indicated that the region where surfers felt wettest was impacted by wetsuit thickness; individuals wearing 3 mm and 4 mm wetsuits were significantly less likely to report that they felt wettest at their abdomen vs their head/neck ($p = 0.041$

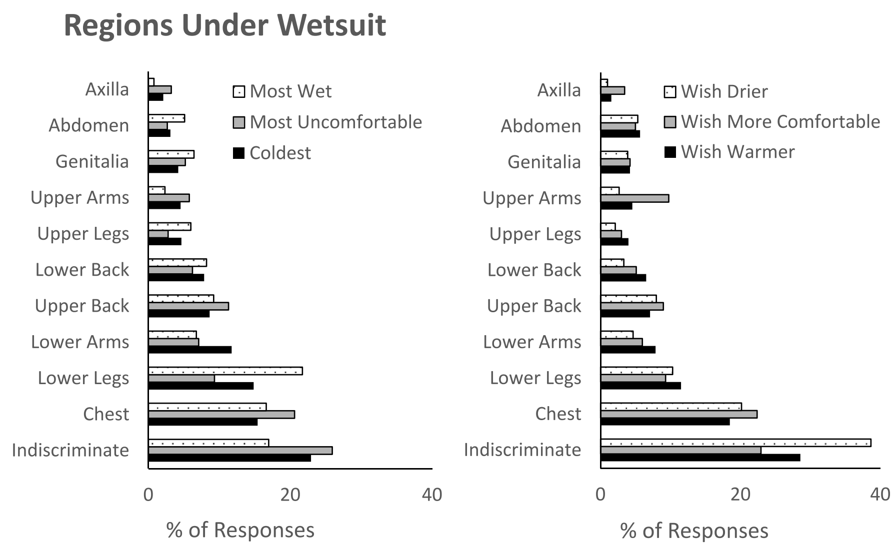


**Fig. 2.** Coldest, most uncomfortable, and wettest anatomical regions indicated by recreational surfers following a surf session (left). Anatomical regions that surfers wished were warmer, more comfortable, and drier following a surf session (right). All responses refer to regions covered by the wetsuit only (n = 903).

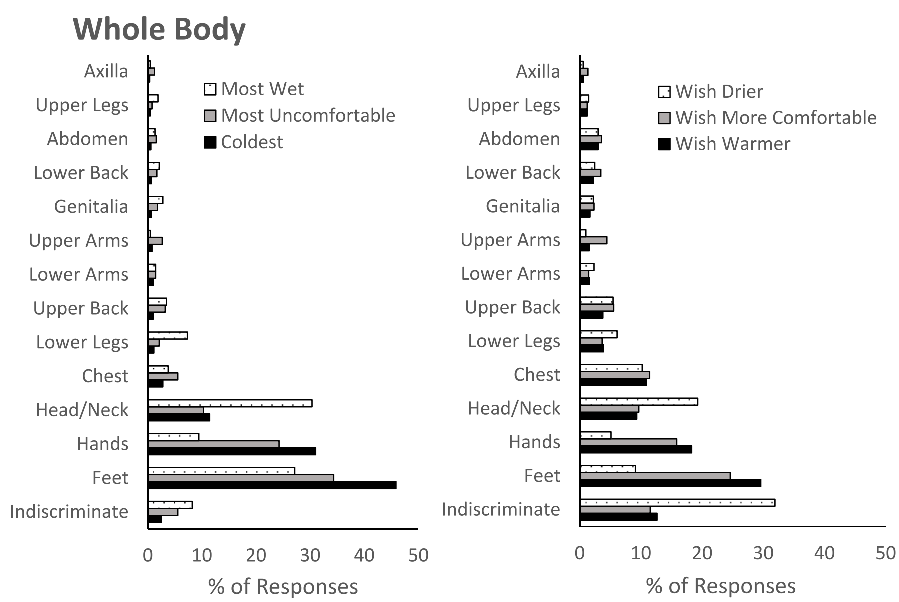


**Fig. 3.** Coldest, most uncomfortable, and wettest anatomical regions indicated by recreational surfers after a surf session (left). Anatomical regions that surfers wished were warmer, more comfortable, and drier following a surf session (right). All responses refer to the entire body (n = 903).

**Table 5**
Accessory use vs Wetsuit Thickness and Water Temperature.

| Wetsuit Thickness | Mean Water Temp (°C) | Bootie Use (%) | Any Accessory Use (%) | Coldest Region = Feet | Coldest Region = Hands |
|---|---|---|---|---|---|
| **2 mm** (n = 13) | 17.5 ± 1.1 | 0% | 0% | 53.8% | 0% |
| **3 mm** (n = 460) | 17.5 ± 1.7 | 9.3% | 12.0% | 49.8% | 25.2% |
| **4 mm** (n = 372) | 15.6 ± 2.7 | 33.9% | 38.2% | 43.0% | 36.6% |
| **5 mm** (n = 58) | 12.5 ± 1.4 | 72.4% | 82.8% | 31.0% | 48.3% |
| **Total** (n = 903) | 16.4 ± 2.5 | 23.4% | 27.1% | 45.9% | 31.0% |

and 0.049, OR = 0.0.002 and 0.004 for 3 mm, 4 mm, respectively, Table 5).

Wetsuit thickness also influenced whole body thermal sensation and thermal comfort. Surfers wearing a 3 mm, 4 mm, or 5 mm wetsuit were less likely to respond with a thermal sensation rating between 5 and 10 (warm) compared with a rating of neutral (range $p < 0.001$ to $p = 0.019$, OR<0.001 to 0.050). Surfers wearing a 3 mm, 4 mm, or 5 mm wetsuit were also less likely to report feeling *Very Comfortable* compared with a response of *Comfortable* ($p < 0.001$, $p = 0.001$, & $p = 0.002$, OR = 0.050, 0.051, & 0.061, respectively). Conversely, surfers wearing a 2 mm wetsuit were more likely to report feeling *Just Comfortable* compared to *Comfortable* ($p = 0.008$, OR = 32.4).

Wetsuit entry (i.e. zipper design) did not have a significant impact on where surfers felt coldest, most uncomfortable, or wettest over their entire body when the variables of water temperature and air temperature were held at a fixed value. However, a non-significant trend was noted among the three types of zipper design: a greater percentage of surfers wearing wetsuits with chest zip indicated they were coldest (16.1%) and wettest (18.6%) at the chest when compared to back zip (cold: 14.8%, wettest: 12%) and zipperless wetsuits (cold: 10.6%, wettest: 14.1%, Table 6). A similar, non-significant trend was noted for surfers wearing back zip wetsuits; a greater percentage of surfers indicated they were coldest (13.9%) and wettest (14.4%) at the upper back when compared to chest zip (cold: 6.4%, wettest: 7.5%) and zipperless (cold: 11.8%, wettest: 8.2%) wetsuits. Surfers wearing zipperless wetsuits were also more likely to respond "indiscriminate" when asked which region felt wettest when compared to the other two variations of wetsuit entry (zipperless: 21.2%, back zip: 16.7%, chest zip: 16.2%, not statistically significant). Wetsuits with different entry designs also varied with age; on average back zip wetsuits were older (2.5 ± 3.2 years) when compared to chest zip (1.6 ± 1.7 years) or zipperless (1.6 ± 1.6 years) wetsuits (Table 6).

Wetsuit entry (zipper location) influenced whole body thermal sensation but not thermal comfort. The regression model indicated that surfers who wore a back zip wetsuit were significantly more likely to rate their thermal sensation as either −5 ($p = 0.025$, OR = 12.46) or −2 ($p = 0.018$, OR = 7.06), compared with a rating of 0 (neutral). Surfers wearing a zipperless wetsuit were also more likely to rate their thermal sensation as −2 (cold) compared to neutral ($p = 0.037$, OR = 6.34). Conversely, individuals wearing a chest zip wetsuit were significantly less likely to rate their thermal sensation as a −4 (cold) compared with a reference of neutral ($p = 0.019$, OR = 0.015).

Use of accessories was related to both water temperature and wetsuit thickness (Table 5). Surfers who wore a thicker wetsuit were more likely to also wear booties or another accessory. As wetsuit thickness increased, a greater percentage of surfers indicated that their hands were the coldest region and fewer surfers indicated that their feet were the coldest region when considering their entire body. This result may be related to the increased likelihood that they were wearing booties. Multinomial logistic regression indicated that surfers who wore booties were more likely to indicate that their hands were the coldest region of their body rather than their feet ($p < 0.001$, OR = 87.56).

Surfers who wore booties, gloves, and/or hood were significantly less likely to indicate that they were most uncomfortable at the hands (range $p < 0.001$ to $p = 0.036$, OR = 0.012 to 0.094) or were indiscriminate (range $p = 0.019$ to $p = 0.034$, OR = 0.003 to 0.018) rather than indicating that their feet were uncomfortable. Surfers who wore no accessories were significantly less likely to report that regions other than their feet were most uncomfortable (chest: $p = 0.020$, OR = 0.001, hands: $p < 0.001$, OR = 0.012, lower arms: $p = 0.038$, OR<0.001, lower legs: $p = 0.036$, OR<0.001, upper back: $p = 0.015$, OR<0.001). Relative to the head/neck, surfers who wore booties were less likely to indicate that another region of their body felt wettest, including abdomen ($p = 0.006$, OR = 0.001), chest ($p = 0.028$, OR = 0.022), lower legs ($p = 0.012$, OR = 0.043), upper legs (p0.034, OR = 0.006), and upper back ($p = 0.001$, OR = 0.004). Accessory use had little impact on whole body thermal comfort or sensation (Table 7).

Twenty three percent of participants wore booties in this study (n = 211), yet many of these individuals reported their feet as the coldest (23.2%), most uncomfortable (22.3%), and wettest region (18.0%). Further, of those who chose to wear gloves (n = 23), 39.1% reported their hands as the coldest, 26.1% reported them being the most uncomfortable, and 21.7% reported them as feeling the wettest. Lastly, of those who wore hoods (n = 115), 13.9% also reported their heads as the coldest, 14.8% as the most uncomfortable, and 20.0% as feeling the wettest.

## 4. Discussion

Surfing in cold water environments has made wetsuits a standard piece of surfing equipment. It is well understood that heat loss occurs heterogeneously across the body during the activity of surfing, yet there is a lack of research characterizing the impact that wetsuits have on thermal perception in aquatic athletes. Wetsuits can be designed with increased neoprene thickness around areas of the body where the most heat loss occurs (Table 1), but wetsuit designers currently have no data associated with thermal comfort and sensations perceived during surfing that can inform wetsuit construction. The present study is the first to characterize the perception of heat loss, comfort, and wetness in recreational surfers wearing wetsuits. The survey results did not support the hypothesis that a surfer's thermal sensation and comfort would align with previously reported changes in skin temperature. The results did indicate that certain aspects of wetsuit design and use of accessories can impact thermal and/or wetness perception.

### *4.1. Whole body thermal sensation and comfort*

Analysis of whole-body thermal sensation (mean 0.8 ± 4) and comfort (mean 1.5 ± 1.2) indicated that most surfers were relatively comfortable on average (Fig. 1). This suggests that surfers have learned to optimize their thermal comfort with respect to their environmental conditions by selecting an appropriate wetsuit and accessories. This result is important to consider because most of the surfers surveyed were clustered around the center of both the thermal sensation and comfort scales, resulting in a platykurtic and compressed distribution (Fig. 1). This presents a challenge to the analysis of data because it limits the resolution of sensation and comfort ratings. Future research into wetsuit perception would benefit from a greater number of surfers on the tails of the thermal sensation and comfort curves, as well as instruments that can more effectively distinguish minor differences in perception for surfers who may report similar levels of comfort.

### *4.2. Anatomical differences in thermal sensation and comfort*

Analysis of the anatomical regions that surfers felt were coldest under their wetsuit revealed that several of their responses aligned with previously reported changes in skin temperature that occur during a typical surf session (Table 4). Specifically, the lower legs or calves were previously found to lose a significant amount of heat (≈5.5–6 °C) because these regions are submerged more frequently than other regions of the body (Corona et al., 2018; Warner et al., 2019). The current perception data were consistent with this result, as a relatively high percentage of surfers (14.8%) indicated that they felt coldest in their lower leg (Table 4, Figs. 2 and 3). However, the chest was previously shown to only lose around 2 °C (Corona et al., 2018; Warner et al., 2019) yet was also consistently rated as one of the top places where surfers felt coldest in the current data (15.4%). Further, the abdomen was previously shown to lose approximately 5–5.5 °C yet was rated by very few

**Table 6**
Wetsuit entry method.

| Entry Mode | Mean Water Temp (°C) | Wetsuit Age (years) | Mean Thermal Sensation | Mean Thermal Comfort | Coldest Region = Chest | Coldest Region = Upper Back |
|---|---|---|---|---|---|---|
| **Back Zip** (n = 216) | 17 ± 2.1 | 2.5 ± 3.2 | 0.5 ± 3.6 | 1.4 ± 1.3 | 14.8% | 13.9% |
| **Chest Zip** (n = 602) | 16 ± 2.6 | 1.6 ± 1.7 | 0.8 ± 3.5 | 1.5 ± 1.3 | 16.1% | 6.4% |
| **Zipperless** (n = 85) | 17 ± 2.1 | 1.6 ± 1.6 | 1.1 ± 3.5 | 1.8 ± 1.0 | 3.5% | 11.8% |
| **Total** (n = 903) | 16.4 ± 2.5 | 1.8 ± 2.2 | 0.8 ± 3.6 | 1.5 ± 1.2 | 15.2% | 8.7% |

**Table 7**
Accessory Use vs Thermal Sensation and Comfort (Whole Body).

| Accessory | Mean Water Temp (°C) | Mean Thermal Sensation | Mean Thermal Comfort | Coldest Region (%) | Most Uncomfortable Region (%) | Wettest Region (%) |
|---|---|---|---|---|---|---|
| **None** (n = 658) | 17.3 ± 1.8 | 1.1 ± 3.6 | 1.5 ± 1.3 | Feet (53.4%) | Feet (38.6%) | Head/Neck (31.8%) |
| **Booties Only** (n = 121) | 14.6 ± 2.8 | −0.2 ± 3.1 | 1.5 ± 1.1 | Hands (56.2%) | Hands (38%) | Head/Neck (33.9%) |
| **Hood Only** (n = 34) | 15.3 ± 2.6 | 0.3 ± 3.7 | 1.2 ± 1.2 | Feet (47.1%) | Feet (26.5%) | Head/Neck (29.4%) |
| **Booties + Other** (n = 90) | 12.4 ± 1.2 | −0.4 ± 3.6 | 1 ± 1.3 | Hands (58.9%) | Hands (54.4%) | Hands (31.1%) |
| **Total** (n = 903) | 16.4 ± 2.5 | 0.8 ± 3.6 | 1.5 ± 1.2 | Feet (45.9%) | Feet (34.3%) | Head/Neck (30.4%) |

surfers as the region where they felt coldest (3.1%).

There are a number of factors that might contribute to these apparent discrepancies between skin temperature and thermal perception. First, it should be noted that there are differences in environmental and wetsuit factors between the experiments compared in Table 4. For example, all of the surfers included in previous studies wore 2 mm wetsuits (Corona et al., 2018; Warner et al., 2019), while the majority of participants (99%) in the current study wore wetsuits that were 3 mm or thicker. In addition, data collection occurred in Southern California for both prior studies but the current analysis included surfers from Southern, Central and Northern California. This likely impacted water and air temperature, as well as wind speed. Next, it is possible that surfers may be more sensitive to cold in the chest, and less sensitive to cold in the abdomen. This seems unlikely, however, because other studies of thermal sensitivity indicate that men and women are not more sensitive to cold in the chest when compared to the abdomen (Luo et al., 1672). The discrepancy between skin temperature and thermal perception may be related to perception of wetness, since more surfers felt wettest and wished they were drier at the chest when compared to the abdomen (Figs. 2 and 3). Prior research indicates that humans cannot directly sense wetness but infer it based upon thermal sensation and their sense of touch (Filingeri et al., 2014; Filingeri and Havenith, 2015). Therefore, wetness perception varies across regions of the torso and exhibits a spatial pattern that is similar to thermosensitivity to cold (Filingeri et al., 2014). However, this result is also unexpected because body position during paddling and resting phases of surfing produces a gravitational gradient that causes water entering the wetsuit to move inferiorly away from the chest and towards the abdomen, pelvis, and legs. Finally, these results might be related to the dynamic aspect of water exposure, which varies among anatomical regions. Water that has been trapped under the wetsuit against the body is warmed over time as a byproduct of metabolism (Naebe et al., 2013). Water that has infiltrated the wetsuit more recently is therefore colder, and anatomical regions near water entry points such as the neck, wrists, and feet may be exposed to colder water more frequently when compared to regions that are more distal from the entry points, such as the abdomen. It is possible that frequent cycling of cold water at the chest, forearms, and calves may influence thermal sensation and comfort. For example, prior research has shown that restriction of water infiltration using wrist cuffs results in higher skin temperatures at the forearm when compared to no cuffing (Kellogg et al., 2020). Further study is needed to assess and measure the amount of water that infiltrates through the neck, extremities, and zippers in greater detail to fully understand discrepancies between reported skin temperature and perceptual data in these regions.

Generally speaking, the anatomical regions most frequently identified as coldest were also identified frequently as most uncomfortable and wettest (Figs. 2 and 3). However, some differences were noted when regions identified as coldest, most uncomfortable, and wettest were compared with regions that surfers wished were warmer, more comfortable, and drier. For example, when evaluating their entire body only 4% of surfers indicated that they felt coldest and wettest in the chest, while 10% of surfers indicated that they wished their chest was warmer and drier (Fig. 3). In addition, 44% of surfers indicated that their feet were the coldest region, yet only 30% indicated that they wished their feet were warmer. This may be due to differences in tolerance to cold or discomfort, as surfers may prioritize comfort at the chest over comfort at the feet. In such cases the temperature changes and wetness may be perceived accurately at a particular region but may not be interpreted as uncomfortable and the surfer may prefer greater warmth and dryness in another region. This response may also be due to a misunderstanding of the survey question. Some surfers may have felt it more appropriate to respond that they preferred to be warmer or drier under an area that was covered by the wetsuit, as the feet, hands and head/neck were all rated more frequently as coldest/most uncomfortable/wettest than they were rated as areas that surfers wished were warmer/more comfortable/drier (Fig. 3). Finally, it should also be noted that there was a large increase in the number of surfers who were “indiscriminate” when identifying areas that they wished were warmer, more comfortable, and wettest, suggesting that they did not have a strong preference for any particular region.

These data indicate that there is a complex interaction between thermal sensation and comfort, particularly when compared across anatomical regions in a recreational surfer. In addition, they indicate that wetsuit design should not be based solely on changes in skin temperature, as these data are not consistently aligned with thermal perception. It is also likely that the type of material on the interior of the wetsuit can influence thermal comfort and sensation in surfers. Prior research indicates that the rate of heat transfer between the skin and a material can impact thermal perception (Ho, 2018), and materials that are often used to line wetsuits such as polyester fleece and nylon jersey have been shown to exhibit different insulation properties (Denny et al., 2022; Lafere et al., 2021). This variable was not accounted for in the current data and should be considered in future analyses.

### 4.3. Wetsuit factors and thermal sensation and comfort

The current results indicate that surfers typically select the appropriate wetsuit thickness for a given set of environmental conditions. While wetsuit thickness varied among participants, there was a moderate to strong relationship between wetsuit thickness and water temperature ($r = -0.517$) and most surfers were relatively comfortable (Table 5). As expected, surfers tend to wear thicker wetsuits when the water is colder, but when water and air temperature were included as covariates in the logistical regression model wetsuit thickness still exhibited a significant impact on thermal sensation and comfort. Future analysis should seek to include greater variation in wetsuit thickness vs water temperature. As an example, an intentional mismatching of wetsuit thickness with environmental conditions might be used to promote more “uncomfortable” situations. Future research should also investigate differences in thermal perception between wetsuits that vary in thickness across different anatomical regions (for example 4/3/2 mm vs 4/3 mm).

Wetsuit entry (i.e. zipper location) also exhibited a significant impact on thermal sensation. Surfers who wore a back zip wetsuit were more likely to rate their thermal sensation as colder when compared to surfers wearing other zipper designs. This may be the result of zipper location or zipper length as back zippers may be longer than other designs and provide a greater perimeter for potential water infiltration. For back and chest zip wetsuits, regions closer in proximity to the zipper were perceived more often to be coldest and wettest, but these differences were not statistically significant. These results suggest that zippers may be somewhat susceptible to water infiltration. The non-significant increase in the frequency of surfers reporting that regions closest to the zipper were coldest may also be due to variations in the quality of the wetsuit zipper, which can vary by wetsuit brand and age of the wetsuit (Table 6). Finally, these non-significant results may also be related to a compression of thermal sensation and comfort scores around the comfortable and neutral values in each scale (Fig. 1). Additional research is needed to quantify water infiltration through the zipper, and to determine whether zipper location interacts with wetsuit thickness.

Surfers indicated that coldest, most uncomfortable, and wettest regions over the whole body were primarily concentrated on areas not covered by the wetsuit (feet, hands, head/neck), suggesting that the greatest potential for improving the comfort of surfers may lie in the use of accessories. The data indicate that use of accessories impacted where surfers felt coldest but appeared to have little effect on whole body thermal sensation or comfort (Table 7). Nearly half (45%) of the 903 participants reported their feet as the coldest region on their entire body, however only 23% (n = 211) chose to wear booties. In addition, 31% of the study population reported their hands as the coldest region but only 2% (n = 23) chose to wear gloves. Lastly, 11% of surfers reported their head as the coldest region but only 12% (n = 115) of the population chose to wear a hood. These findings suggest that future research should aim to elucidate why a majority of surfers choose to not utilize accessories such as booties, gloves, and hoods to aid in thermoregulation during surfing.

Surf booties were the most frequently utilized wetsuit accessory (Table 7). The data indicate that wearing booties can impact thermal comfort at the feet, since fewer bootie wearers responded that their feet were coldest despite surfing in colder water on average than non-bootie wearers (Table 7). Anecdotal evidence suggests that some surfers avoid wearing booties because they can attenuate the sensory feedback from the bottom of the feet as they interact with the surface of the board. However, it is also likely that decreases in skin temperature can lead to a decrease in sensation at the bottom of the foot (Schlee et al., 2009), and prior research has shown that decreases in muscle temperature can lead to decreases in strength (Bennett, 1984; Holewijn and Heus, 1992). Conversely, increases in skin temperature on the foot have been shown to improve tactile sensitivity and postural control (Machado et al., 1020). Additional research is needed to clarify the benefits vs cost of wearing booties during a recreational surf session. Taken together, these data also suggest that wetsuit booties are a piece of surfing equipment with a large potential for design improvement.

It should be noted that this survey did not account for the impact that thermal changes may have on surfing performance, which may vary across anatomical regions. Notably, the foot interacts directly with the board to help the surfer maintain balance and to manipulate the board's motion. Therefore, it is likely that changes in thermal sensation at the foot would have a greater impact on surfing performance than changes that occur at the upper back, for example. If wearing booties has little effect on overall comfort but results in fewer surfers indicating that their feet are coldest, this may be a preferable outcome. Additional study is needed to understand the relative impact that changes in temperature and thermal sensation may have on a surfer's ability to perform, and to understand the importance of performance related variables when compared with thermal perception.

## 5. Conclusions

These results suggest that surfers wearing wetsuits are generally warm and comfortable during recreational surfing. Surfers' perception of thermal discomfort was most often focused in anatomical regions not covered by the wetsuit (feet, hands, and head), suggesting that surfers might further improve their comfort by wearing accessories such as booties, gloves, and hoods. Under their wetsuits, surfers felt the most thermal discomfort in anatomical locations that are near access points and zippers (chest, lower legs, upper back, and lower arms). Future studies should utilize instruments for thermal comfort and sensation that have greater resolution so as to distinguish more clearly between surfers that report similar levels of comfort. Future work should also control more carefully for specific environmental factors and assess water infiltration and circulation to better understand the mechanisms behind the current perceptual data. Finally, future studies should also focus on the interaction between thermal perception and surfing performance.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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