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Impact of Velcro Cuff Closure on Forearm Skin Temperature in Surfers Wearing a 2 mm and 3 mm Wetsuit

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ABSTRACT

International Journal of Exercise Science 13(6): 1574-1582, 2020. Surfing is a worldwide sport that often requires participants to wear a wetsuit to assist in thermoregulation. In a recent study, forearm skin temperature decreased by approximately 3 °C while wearing a wetsuit during recreational surfing. The purpose of this study was to test the hypothesis that reducing water flow in and out of the wetsuit by cuffing the wetsuit at the wrist, with a novel cuff closure system (Velcro cuff), would result in greater forearm skin temperature while surfing. One hundred and twelve (94 male, 18 female) recreational surfers between the ages of 18-50 participated in this study. Forearm skin temperature was measured at 1-minute intervals across the surf session in both arms with four wireless iButton thermal sensors located two inches from the styloid process (wrist) and olecranon process (elbow). Following instrumentation, all subjects had one of their wrists randomly cuffed with a one-inch wide Velcro cuff that was tightened to 2 cm less than the circumference of the wrist plus wetsuit. Subjects were then instructed to engage in regular recreational surfing activities for a minimum of 30 minutes at seven beaches in North San Diego County from October to April. No significant differences were found between the average cuffed wrist skin temperature and the average uncuffed wrist skin temperature (p = 0.06). However, average cuffed forearm skin temperature was significantly higher than average uncuffed forearm skin temperature (p = 0.01). Results from this study suggest that cuffing the wrist of wetsuits is a simple technique that can be utilized by surfers to significantly improve forearm skin temperature during surfing. These findings may also have an implication on future wetsuit designs.

KEY WORDS: Action sports, wrist, forearm, closure

INTRODUCTION

Wetsuits are an important piece of equipment in the sport of surfing since they allow surfers to maintain adequate body temperatures in both cold water and ambient air temperatures (10). Standard wetsuits are made of neoprene and mitigate heat loss during surfing by providing both an additional layer of insulation and trapping small amounts of water between the wetsuit and skin to be warmed by the body (10). The effectiveness of wetsuits in maintaining skin temperatures during surfing has recently been characterized in both male and female surfers during recreational surfing (2, 11). The results from these studies suggest that heat loss across the body is heterogeneously distributed and that the regions of the body that have the greatest reductions in skin temperature are those that interact with the water the most (2, 11). Therefore, it is not surprising that large reductions in skin temperature during surfing have been reported in the arms and legs (2, 11), given the fact that paddling comprises approximately 50% of the time spent surfing (4, 6, 7). Interestingly, it has been reported that greater reductions in skin temperature occur in the distal portion of the extremities (forearm ~9-14%, calf ~18-19%) when compared to proximal portion of the extremities (upper arm ~5-6%, thigh ~15-16%) (2, 11). These differences in skin temperatures across the extremities may be a result of water infiltration through the wrist and ankle cuffs during surfing. Wetsuit manufacturers have spent decades attempting to design wetsuits that can decrease water infiltration through key access points (wrist, ankle, and neck). Xcel Wetsuits (XcelWetsuits Haleiwa, HI) "Drylock" and "Nexskin" seals are examples that have been advertised to reduce water infiltration through the wrist and ankle cuffs, respectively. However, there is no empirical evidence to suggest that any design solution for limiting water infiltration through wetsuit access points would be effective at reducing heat loss in the extremities during surfing. Therefore, the purpose of this study was to determine the impact from applying a novel closure system (Velcro cuff) around the wrist cuff of a full suit wetsuit on forearm skin temperature during recreational surfing. We hypothesized that minimizing water infiltration through the sleeve opening by tightening a Velcro cuff around a full suit wetsuit sleeve would significantly increase forearm skin temperature while surfing.

METHODS

Participants

One hundred and twelve recreational surfers (94 males and 18 females) ages 18-50 were recruited for this study. Before participating, all subjects provided written consent to participate in the study. The experimental procedure was approved by the California State University-San Marcos Institutional Review Board (#1302241). Subjects also completed a two-page questionnaire regarding the subject's age, height, weight, surfing experience, and wetsuit information. All subjects were required to have at least one year of surfing experience and be willing to surf for at least 30 minutes continuously during data collection.

Data for 96 out of 112 subjects were used in the final analysis (78 males and 18 females). Data for sixteen subjects were excluded for at least one of the following reasons: 1) data were lost from one or more thermistors (n = 6), 2) the subject did not surf for at least 30 minutes (n = 2), 3) the subject wore an extra layer under their wetsuit (n = 3), or 4) the subject wore a watch around their uncuffed wrist (n = 1), 5) the subject's wetsuit information was inaccurately recorded (n=1), 6) the subject's surfing duration was inaccurately recorded (n = 1), 7) the subject admitted to adjusting their cuff tightness while surfing (n = 1), 8) the subject's age exceeded study criteria (n = 1). The average age, height, weight, and surfing experience of the subjects was 30.97 ± 9.63 years, 176.98 ± 8.52 cm, and 75.18 ± 13.37 kg, 13.96 ± 10.36 years, respectively. The sleeve thickness of wetsuits worn by the subjects during their surf sessions were 2 mm (n = 55) and 3 mm (n = 41).

Protocol

After providing written consent and completing the questionnaire, four iButton thermistors (type DS1921G; Maxim Integrated/Dallas Semiconductor Corp. USA) were placed on both forearms. The first pair of thermistors were placed 2 inches proximal to the styloid processes on the dorsal side of the forearms to measure wrist skin temperature. The second pair of thermistors were placed 2 inches distal to the olecranon processes on the dorsal side of the forearms to measure forearm skin temperature (Figure 1). Measurements for thermistor placement were made using a standard cloth measuring tape. Thermistors were held in place using 3M waterproof adhesive tape (NexcareTM TegadermTM, USA) and skin temperatures were recorded at 1-minute intervals throughout the surf session. Wrist circumference of a randomized arm was measured over the distal end of the wetsuit arm sleeve. A Velcro cuff (1″x12″, Gadget Beyond, USA) marked in centimeters along its length was placed over the end of the wetsuit sleeve and tightened to a circumference 2.0 cm smaller than the original measurement taken over the wetsuit. The 2.0 cm tightness was determined through pilot studies, which revealed neoprene compression at this length still allowed full range of motion to the surfer's wrist with minimal discomfort. Subjects were instructed to surf for a minimum of 30 continuous minutes, abstaining from adjusting the cuff during their session. Subjects were advised to surf as they would under normal conditions; no instructions were given regarding their activity in the water. Session time was recorded when each subject entered and exited the water at ankle height. After the subjects completed their surfing session, the subject's cuff was checked for tightness to make sure it had not been adjusted. Data from all four thermistors were downloaded and copied into a Microsoft Excel Spreadsheet for data analysis. Environmental conditions including ambient air temperature, relative humidity, weather, water temperature, wave height, wave interval, wave direction, wind speed, and wind direction were obtained at the beginning of each data collection session directly from the National Weather Service and the National Oceanic and Atmospheric Administration's buoys located offshore (Surfline.com). All data were collected across seven beaches in North San Diego County from October to April.

Skin temperature data was obtained and downloaded from the thermistors using the OneWireViewer (Maxim Integrated/Dallas Semiconductor Corp., USA) JavaTM application. Only the skin temperature measurements recorded within the start and end time of each subject's surfing session were utilized.

Statistical Analysis

All subjects surfed for at least 45 minutes during their session. Therefore, data from each sensor were reduced into 9 epochs of time by taking the average temperature across each 5-minute interval from minute 1 to minute 45. Two-way repeated measures ANOVA (2 within-subject factors) were then used to compare cuff (2 conditions) x time (9 epoch averages) for both the forearm and wrist sensor data. The Greenhouse-Geisser adjustment was applied in cases where the assumption of sphericity was violated. Significant ANOVA results were followed up with paired t-tests comparing cuffed and uncuffed temperature at each time point. The Benjamini-Hochberg analysis was utilized to control for false discovery rate due to multiple comparisons (1).

A separate analysis was performed to investigate the impact of wetsuit arm thickness on the effects of the novel closure system applied to the cuff of the wetsuit sleeve. Participants were divided into a 2 mm and 3 mm group, based upon their wetsuit characteristics. The mean skin temperature recorded by each of the 4 sensors was calculated across the entire trial. These means were compared between the cuffed and uncuffed arm for both wetsuit thickness groups using paired t-test (α = 0.05).

This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (10).

Figure 1. Thermistor placement.

RESULTS

The average duration of all individual surf sessions (n = 96) was 69.3 ± 23.6 minutes. The average water temperature was 16.7 ± 2.0 °C, with an average wave size of 0.7 ± 0.2 m, an average wave interval of 12.8 ± 3.1 sec, and an average wave direction of 224 ± 34°. Averages for air temperature, wind speed, wind direction, and humidity were 16.1 ± 2.6 °C, 3.9 ± 2.5 kt, 160 ± 107°, and 70± 19% respectively.

Two way repeated measures ANOVA indicated that there were significant differences for the main effect of time ($F_{1.68,153.27}$ = 60.782, p < 0.001, $\eta^2_{partial}$ = 0.400) and the main effect of cuff condition ($F_{1,91}$ = 8.636, p = 0.004, $\eta^2_{partial}$ = 0.087) for forearm skin temperature. The interaction of time by cuff was not significant ($F_{2.443,222.34}$, = 1.069, p = 0.355, $\eta^2_{partial}$ = 0.012) at the forearm. Post hoc analysis revealed significant differences between the cuffed and uncuffed conditions at every time point except for the first 5-minute epoch (Figure 2). Data from the final epochs for 4 participants were not included in the analysis because they did not surf for at least 45 minutes.

Two way repeated measures ANOVA indicated that there were significant differences for the main effect of time ($F_{1.739,158.28}$ = 104.952, p < 0.001, $\eta^2_{partial}$ = 0.536), the main effect of cuff conditions ($F_{1,91}$ = 136.793, p > 0.001, $\eta^2_{partial}$ = 0.601), and the interaction of time x cuff ($F_{2.604,236.93}$ = 8.726, p < 0.001, $\eta^2_{partial}$ = 0.088) for wrist skin temperature. However, after controlling for false discovery rate using the Benjamini-Hochberg procedure, none of the differences between the cuffed and uncuffed conditions were significant at any time point (Figure 3).

Among the 41 subjects who wore 3mm wetsuit arm sleeves, no significant difference (p = 0.58) was found between the average cuffed wrist skin temperature (27.5 ± 1.9 °C) and the average uncuffed wrist skin temperature (27.1 ± 3.0 °C) (Figure 4). In addition, no significant difference (p = 0.33) was found between the average cuffed forearm skin temperature (30.3 ± 2.0 °C) and the average uncuffed forearm skin temperature (30.1 ± 2.0 °C) (Figure 4).

In contrast, among the 55 subjects who wore 2mm wetsuit arm sleeves, significant difference was found (p = 0.03) between the average cuffed wrist skin temperature (26.9 ± 1.8 °C) and the uncuffed wrist skin temperatures (26.5 ± 2.2 °C) (Figure 4). In addition, significant difference was found between the average cuffed forearm skin temperature (29.3 ± 2.1 °C) and the uncuffed forearm skin temperature (28.7 ± 2.5 °C) (p = 0.01, Figure 4).

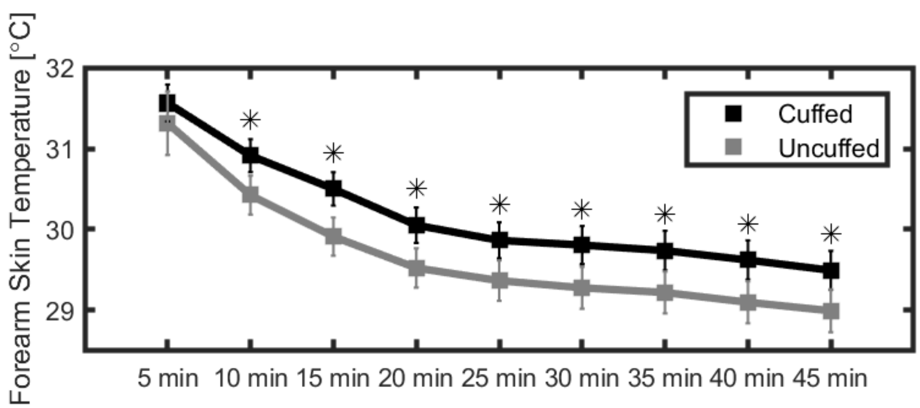

Figure 2. Temperature comparisons across time between the cuffed and uncuffed forearm in all participants (n = 96). Bars represent standard error of the mean. Asterisk (*) indicates significance at a p-value ≤ 0.05.

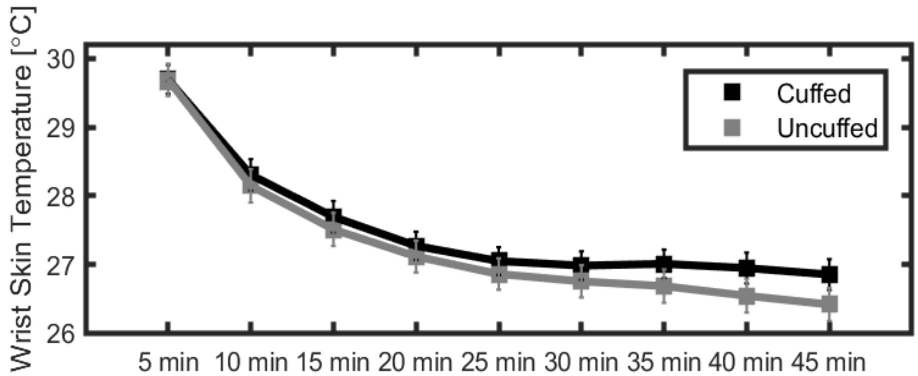

Figure 3. Temperature comparisons across time between the cuffed and uncuffed wrist in all participants (n = 96). Bars represent standard error of the mean.

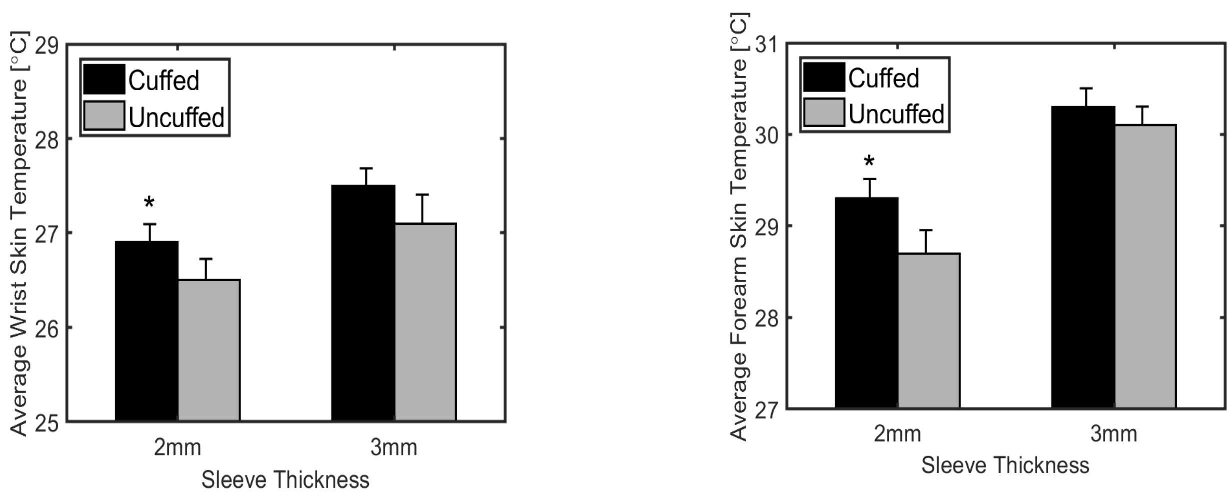

Figure 4. Temperature comparisons between the cuffed and uncuffed wrist (left) and forearm (right) in 2 mm wetsuit sleeve thicknesses (n = 55) and 3 mm wetsuit sleeve thicknesses (n = 41). Bars represent standard error of the mean. Asterisk (*) indicates significance at a p-value ≤ 0.05.

DISCUSSION

It has previously been reported that forearm skin temperatures decrease during a surf session by approximately 3 to 4 °C in recreational surfers wearing a 2 mm thick wetsuit (2, 11). Reductions in skin temperature of this magnitude may cause a decrease in surfing ability and thermal comfort. Water infiltration through the cuff of the wetsuit may contribute to these significant decreases in forearm skin temperature while surfing. To combat this phenomenon, wetsuit companies are currently marketing new wetsuit designs, containing a modification around the wetsuit sleeve, as a method to reduce heat loss in the forearms. Currently, there is a paucity of research analyzing the effectiveness of these wetsuit modifications to combat heat loss. Therefore, the purpose of this study was to determine the impact that tightly cuffing the wrist would have on forearm skin temperature during recreational surfing. The primary findings of the current study suggest that limiting water infiltration by tightening a Velcro cuff around a wetsuit sleeve by 2 cm less than the circumference of a wetsuit covered wrist significantly increases lower arm skin temperature across time by a mean difference of approximately 0.5 °C while surfing. While significant differences were observed in forearm skin temperature across epochs, no significant differences were found in wrist skin temperature at any duration after controlling for false discovery rate. One can speculate that these differences in results between the wrist and forearm may be attributed to the inability of the cuff to completely stop water infiltration. These small amounts of water that infiltrated likely interacted with the skin closest to the entry point of the sleeve, but lacked the volume necessary to move further up the arm. Future studies will be necessary to determine the level of neoprene compression required to stop water infiltration through the wrist cuff of wetsuits and if this level of compression has an impact on range of motion and comfort.

An unexpected finding of the current investigation was that there were differences in the effectiveness of the Velcro cuff between subjects that wore wetsuits with 2 mm and the 3 mm arm sleeve thickness. Specifically, the current investigation demonstrates that the Velcro cuff induced significant differences in both wrist and forearm skin temperature amongst subjects who wore a wetsuit with 2 mm arm sleeves while surfing. In contrast, no significant differences in either the wrist or the forearm skin temperature of the cuffed and uncuffed arms were reported in subjects who wore a wetsuit with 3 mm arm sleeves while surfing. These results suggest that a wetsuit made with 3 mm neoprene wrist cuffs may inherently provide greater compression to the wrist compared to 2 mm neoprene and that this additional compression may result in decreased water infiltration. Alternatively, neoprene compression between wetsuits consisting of 2 mm and 3 mm arm sleeves may be similar upon manufacturing and only diverge as the elastic properties breakdown at different rates through use (8, 9). However, it is important to note that both proposed mechanisms to describe the difference in results are purely speculative since neither compression of the cuff nor water infiltration was measured in the current investigation. Future research is necessary to characterize the impact that neoprene compression has on water infiltration through wetsuit access points.

It is important to put the results of the current study in context with previously published data to understand if these significant differences in skin temperature between cuffed and uncuffed wrists could influence thermal comfort and surfing performance. The current data indicates that decreasing water infiltration through the wrist cuff of a wetsuit can increase skin temperature across time by an average of approximately 0.5 °C. Although significant, data from the literature suggests that these modest increases in skin temperature likely do not translate into any physiologically significant outcomes associated with muscle function and surfing performance (3). Specifically, there is strong evidence that changes in muscle temperatures above 27 °C have limited impact on physiological measures of muscle function (3). In addition, it is well documented that underlying skeletal muscle temperatures are typically between 2 to 10 °C above temperatures reported in the skin (3). Therefore, lower arm skin temperatures reported in this study (26-30 °C) likely do not translate to skeletal muscle temperatures that would be impacted by a 0.5 °C increase in temperature induced by wrist cuffing. On the other hand, skin temperature changes as small as 0.003 °C have been reported to produce thermal sensation (5). These finding suggest that increases in forearm skin temperature of 0.5 °C that were induced by cuffing the wetsuit at the wrist were likely perceivable to the subjects and positively affected thermal comfort in the lower arm. This is an important result since it supports the idea that novel wetsuit closure systems, which are currently being utilized by wetsuit manufactures, may result in enhanced thermal comfort of the forearm during surfing. However, it is currently unclear the extent to which these novel wetsuit closure systems enhance forearm comfort since they likely provide less compression and allow for greater water infiltration than the Velcro cuffs used in the current investigation.

This study does possess some limitations despite its strengths. Data from this study may not be applicable to colder locations than those offered in Southern California as water temperatures during surfing can drop well below an average of 16.7 ± 2.0 °C and air temperature of 16.1 ± 2.6 °C observed in this paper. More data is needed to determine if a Velcro cuff system performs consistently across varying surfing water and ambient air temperatures. Additionally, the inability to measure compression and water infiltration was a limitation of the current investigation. However, pilot data suggested that using the Velcro cuff to apply levels of compression greater than those utilized in the current study significantly impacted mobility of the wrist and comfort of the subject. Therefore, it is likely that the compressions achieved with the wrist Velcro cuffing technique used in the current study represents the maximal compression achievable without inducing functional deficits. Lastly, the current study did not take measurements of muscle function or thermal perception. Therefore, conclusions drawn from previous data in these research areas are purely speculative.

The findings from the current study support the hypothesis that limiting water from entering through the wrist of a wetsuit sleeve increases forearm skin temperature while surfing. This is the first study to demonstrate how a Velcro cuff over the opening of a wetsuit can reduce heat loss in an aquatic environment. Specifically, these findings demonstrate that a Velcro cuff better reduces heat loss in thinner wetsuit material than in thicker wetsuit material. Our results also demonstrate that on average, the addition of a Velcro cuff increases forearm skin temperature across a variety of wetsuit brands. However, it is unlikely that the small increase in forearm skin temperature that resulted from cuffing the wrist with a Velcro cuff resulted in any increases in skeletal muscle performance. Reciprocally, these reported changes in skin temperature attributable to wetsuit wrist cuffing likely increased thermal comfort in the forearm of recreational surfers. More importantly, the results of the current study suggest that water infiltration through the wrist access point of the wetsuit only contributes to approximately 15% of the reduction in forearm skin temperature that has been reported to occur in men and women during recreational surfing. Therefore, one can conclude that water infiltration through the access points of the wetsuit only contributes minimally to changes in skin temperature that occur during surfing in a wetsuit. In conclusion, the data from this study suggests that wetsuit manufacturers should consider incorporating a Velcro strap into the design of the wrist cuff in the sleeves of thin wetsuits (≤ 2 mm neoprene thickness) to enhance thermal comfort and skin temperature of the forearm during surfing.

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