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Wearing an Inflatable Vest Alters Muscle Activation and Trunk Angle While Paddling a Surfboard

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Low back pain is a commonly reported problem among recreational surfers. Some individuals report that wearing a vest with an inflatable bladder that alters trunk angle may help to alleviate pain. The purpose of this study was to determine whether such a vest has an effect on muscle activation and extension of the lower back. Twelve recreational surfers completed 12 paddling trials at 1.1 m/s in a swim flume on both a shortboard and a longboard on 2 separate days. Three conditions of no vest, vest uninflated, and vest inflated were presented to participants in random order. Surface EMG and trunk angle were acquired via wireless sensors placed over the right erector spinae, mid-trapezius, upper trapezius, and latissimus dorsi. Wearing the inflated vest affected muscle activation: erector spinae and mid-trapezius demonstrated a significant decrease in activation relative to wearing no vest (12% and 18% respectively, $p < .05$). Trunk extension was also significantly reduced when the vest was inflated (18% reduction, $p < .05$). Results were similar for both the short and longboard, though this effect was greater while paddling the larger board. These results suggest that a properly inflated vest can alter trunk extension and muscle activity while paddling a surfboard in water.

Keywords: water sports, low back pain, erector spinae

By some estimates, between 12 and 20 million individuals participate in the sport of surfing worldwide, with an annual growth of approximately 12% to 16%.[1,2] Detailed demographic information about recreational participants is relatively sparse, but recent data indicate strong participation across several age groups, including older adults.[3,4] During a typical surf session, recreational surfers spend a majority of their time paddling (44–58%) and only 4% to 8% of their time riding waves.[3,5–8] Lying prone on the surfboard while paddling requires repetitive bouts of back, shoulder, and neck extension which place recreational surfers at risk for developing a variety of overuse injuries.[9–11] Despite these data, there is surprisingly little research related to surfing in general, and rehabilitation and injury prevention in particular. Further, few surf-related products have been designed to improve comfort and reduce injury in surfers, and much of the equipment currently available is based upon anecdotal evidence. Therefore, a need exists for research into the development of products that have the potential to improve performance and reduce injury for recreational participants in the sport of surfing.

Low back pain is a common problem among recreational surfers that might be addressed through strategic design of surfing equipment. There is a large body of research focused on the mechanisms of low back pain in the general population,[12–18] but there has been little research into subacute low back pain that can occur during and immediately following bouts of prone activities like surfboard paddling.[9–11] While the etiology of low back pain is complex, data suggest that trunk extensor muscle activity is at least partially related to the subacute pain experienced by surfers. For example, biomechanical models of the trunk indicate that while back extensor muscles primarily act to extend the lumbar spine, they can also generate intervertebral compression which may be one cause of discomfort during physical activity.[19,20] In addition, increased activation of erector spinae during isometric trunk extension has been reported to be a strong predictor of future development of low back pain in asymptomatic individuals.[21] Further, several studies have reported a relationship between electromyographic (EMG) activity in trunk extensor muscles, particularly erector spinae, and low back pain during activities such as locomotion,[15,16] standing,[12,14] lifting,[13,17] and bridging.[18] Though prone paddling is not a weight bearing activity, intervertebral compression remains a concern due to increased levels of back and extensor muscle activity, and surfers have reported low back pain specifically associated with prolonged paddling.[9] It therefore stands to reason that an intervention aimed at reducing muscle activity in back extensor muscles during a surfing session might help to reduce low back pain and allow surfers to participate for longer periods of time.

Based upon this concept, the Ergo Vest™ (Paddleair, Palm Desert, CA) was developed with the goal of reducing low back pain by supporting the trunk with an inflatable bladder located on the anterior aspect of the mid torso, directly over the surfer's sternum (Figure 1). During use, the inflated bladder acts as a 'pillow' situated between the upper torso of the surfer and the deck of the surfboard. Resting a portion of the upper torso on the bladder may therefore help to passively extend the surfer's trunk while paddling, and the Ergo Vest was designed to allow the user to manually inflate and deflate the bladder as needed while paddling in the ocean for extended periods of time. If the bladder can assist the surfer in maintaining the proper prone posture while paddling through passive extension of the trunk, this may result in less muscle activation of back, neck, and shoulder extensor muscles. Further, if pain and discomfort can be reduced by using this device, the athlete may be able to surf longer and realize more of the benefits of physical activity.[3,7,8] Anecdotally, users of this product have reported reductions in back and shoulder pain while wearing

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Figure 1 — The Ergo Vest by Paddleair™.

Figure 2 — Instrumented subject paddling a shortboard in the swim flume without a vest.

this garment, but no scientific data exist to support its ability to reduce pain or discomfort while surfing.

The purpose of this study was to determine whether wearing an inflated Ergo Vest alters trunk extension and the activation of 4 back and/or shoulder extensor muscles while paddling both a small and large surfboard. Based upon the anecdotal evidence reported by users of this product, it was hypothesized that wearing the inflated vest would result in a reduction in activation of one or more of the muscles studied here. Further, it was hypothesized that presence of an inflated bladder between the surfer and the deck of the surfboard would lead to an increase in trunk extension and a decrease in trunk range of motion by mechanically opposing trunk flexion.

Methods

Participants

Twelve male recreational surfers were recruited from the local surfing population (age, 25.3 ± 6.1 y; height, 1.8 ± 0.1 m; mass, 74.7 ± 5.4 kg). Participants indicated that they engaged in surfing for at least 4 hours per week on average and were free of any cardiovascular, musculoskeletal, or neurological condition that might have affected performance. Participants also completed a health history questionnaire (AHA/ACSM Health/Fitness Facility Participation Screening Questionnaire). All procedures were approved by the Institutional Review Board at California State University, San Marcos (IRB# 811015-1) and all participants gave their written informed consent prior to participation.

General Procedures

All paddling trials occurred in fresh water using a modified swim flume (Endless Pool Elite, Fitness Machines, LCC, Aston, PA; Figure 2). Water temperature was maintained between 18°C and 21°C, and flow velocity was set to 1.1 m/s, verified prior to each trial using a flowmeter (Flowatch, NTech USA, Holmen WI). Two different surfboards were used: a shortboard (177.8 cm length, 50.2 cm width, 7.6 cm thick, and 37.36 L volume) and a longboard (243.8 cm length, 57.2 cm width, 8.3 cm thick, 86 L volume). The inflatable vests (Ergo Vest™ by Paddleair, Palm Desert, CA) were sized to each participant according to manufacturer guidelines. For trials that required inflation of the bladder, consistency in air pressure was achieved by performing a predetermined number of strokes with a manual bicycle pump (5 strokes for medium sized vest and 8 strokes for large sized vest). The number of strokes was estimated from pilot testing of vest use by surfers who self-selected their preferred air pressure. Inflation of the bladder did not result in the stretch of other aspects of the vest and did not affect overall compression of the torso or abdomen.

Participants performed a total of 12 paddling trials, each 1 minute in duration. These trials were performed over 2 separate days in order to minimize the effects of fatigue: 6 trials were performed while paddling the shortboard and 6 trials were performed on another day using the longboard. Each data collection session consisted of a 1-minute warm-up and familiarization trial, followed by 2 trials performed under each of the 3 vest conditions (6 trials per session). These conditions were defined as (1) no vest, (2) vest worn but not inflated, and (3) vest worn and inflated. Vest conditions were presented in random order, and participants were given 2 minutes of rest in between trials under the same vest condition, and 5 minutes of rest between vest conditions. Twelve participants completed the shortboard session but only 10 subjects returned to complete the second session with the longboard.

Surface electromyography was used to record activity from the erector spinae (lumbar region), mid trapezius, upper trapezius, and upper latissimus dorsi muscles of the right side of each participant (Figure 2). Electrodes were placed as follows: erector spinae = approximately 3 cm (2 finger widths) lateral to the spinous process of L1; mid trapezius = parallel to muscle fibers between the spine of the scapula and the spinous process of T2; upper trapezius = parallel to muscle fibers at a point approximately 2 cm lateral to the midpoint between spinous process of C7 and acromion; upper latissimus dorsi = parallel to muscle fibers (oblique, ~25°) approximately 4 cm below inferior tip of the scapula and midway between the spine and lateral aspect of the torso.[22] EMG data were captured at 1000 Hz using a Trigno wireless system (Delsys Inc, Natick, MA). In order to protect the sensors, waterproof adhesive bandages were applied over each sensor and directly to the skin (3M Nexcare Tegaderm, Maplewood, MN). Further, analysis was limited to muscles that were kept above water level during the paddling motion to avoid damage to sensors and the interruption of wireless signal between the sensor and the base station. EMG sensors were removed and replaced between data collection sessions that occurred on separate days (ie, between surfboard type), but were kept in place within each session. The integrated accelerometer function of the mid-trapezius sensor was used to determine sensor tilt with respect to gravity. These calculations of tilt angle for the upper back were then used as an estimate of trunk extension for comparison across vest conditions.

Data Analysis

Raw EMG data were rectified and filtered (fourth-order Butterworth, 25 Hz cutoff).[22] The area under the curve for each stroke was averaged across the entire trial. Results from trials performed with the same board and vest condition were then averaged together. Acceleration time series data were also filtered (fourth-order Butterworth, cutoff 20 Hz) and the tilt angle maximum, average, and mean range of motion per stroke were extracted from each trial. Muscle activation and tilt angle were then compared across vest conditions using repeated measures ANOVA, and separate paired *t*-tests were performed post hoc to determine where statistical differences lay. The Benjamini-Hochberg procedure was applied to control for false discovery rate among the results of the ANOVA tests.[23] No comparisons were made between surfboard type because EMG sensors were replaced between sessions.

Results

Several aspects of muscle activation were altered by wearing the inflatable vest. In particular, manipulation of vest condition resulted in significant differences in muscle activity for mid-trapezius while paddling the shortboard ($F_{2,11} = 5.44$, $P = .012$), and erector spinae ($F_{2,9} = 4.08$, $P = .034$) and mid-trapezius ($F_{2,9} = 4.58$, $P = .0247$) while paddling the longboard (Figure 3). Post hoc analysis revealed a significant reduction in mid-trapezius muscle activity for the shortboard condition when the inflated vest condition was compared to the other 2 vest conditions (13% and 15% reduction, paired *t*-test, $P = .018$ and $P = .007$, respectively). For the longboard case, erector spinae activity was significantly reduced when the inflated vest condition was compared to both the no vest and uninflated vest condition (9% and 10% reduction, $P = .012$ and $P = .044$, respectively). Mid-trapezius activity was also significantly reduced when the inflated vest condition was compared to the no vest condition and the uninflated vest condition (8% and 15% reduction, $P = .026$ and $P = .041$, respectively). No differences in muscle activation were noted between any of the no vest and uninflated vest conditions. Wearing the inflated vest also appeared to result in reductions in muscle activity in upper trapezius and latissimus dorsi, but these differences were not statistically significant ($P = .330$ and $P = .055$ for the shortboard, respectively, and $P = .455$ and $P = .593$ for the longboard).

While paddling the shortboard, vest condition did not appear to alter the tilt angle of the accelerometer (eg, $F_{2,11} = 0.16$, $P = .853$ for mean tilt angle, Figure 4). However, range of motion per stroke was significantly different while paddling the longboard ($F_{2,9} = 5.2$, $P = .016$), and post hoc analysis revealed that the inflated vest resulted in a decrease in deviation of the trunk (ie, more static) relative to wearing no vest (18% reduction, paired *t*-test, $P = .039$).

Discussion

These results demonstrate that certain aspects of back extensor muscle activation and trunk extension angle are altered in a prone surfer while wearing a vest with a small inflated bladder between their sternum and the deck of the surfboard. In addition, no

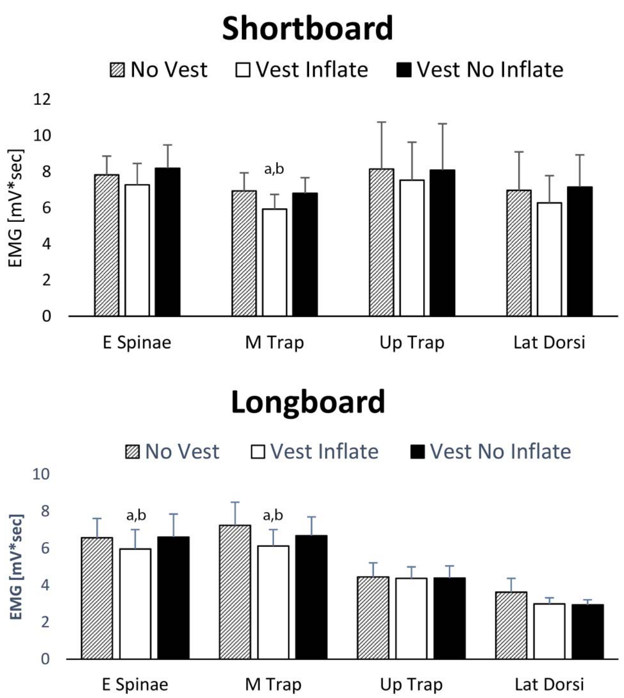

Figure 3 — Muscle activation while paddling a shortboard (top) and longboard (bottom) at a relative velocity of 1.1 m/s. Bars represent standard error of the mean. [a] Statistically significant decrease relative to the no vest condition ($p < .05$). [b] Statistically significant decrease relative to the vest no inflate condition. E Spinae = erector spinae; M Trap = mid-trapezius; Up Trap = upper trapezius; Lat Dorsi = latissimus dorsi; EMG = electromyography.

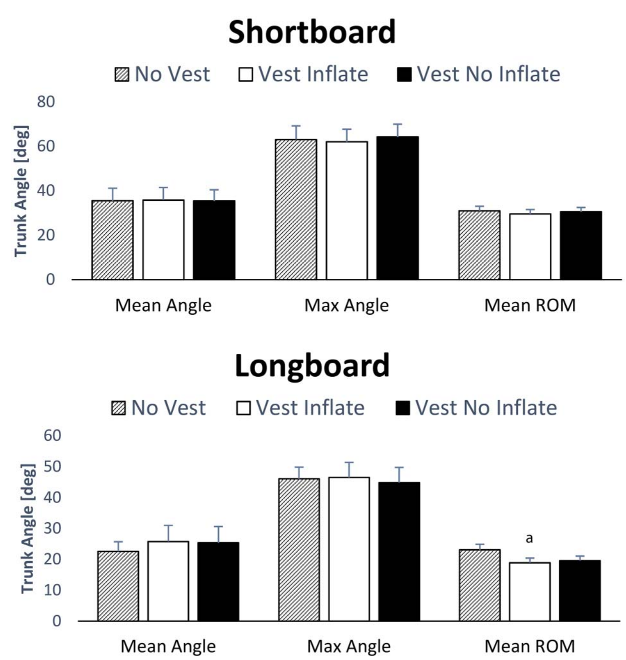

Figure 4 — Measures of trunk extension angle while paddling a shortboard (top) or longboard (bottom) in a swim flume at 1.1 m/s. Trunk angle was calculated from the acceleration data acquired from the electromyography (EMG) sensor placed over the mid-trapezius. Bars represent standard error of the mean. [a] Statistically significant decrease relative to the no vest condition ($p < .05$). Max = maximum; ROM = range of motion.

differences in muscle activation were noted between the no vest and uninflated vest conditions, suggesting that these changes in muscle activity were primarily due to bladder inflation rather than mechanical compression of the trunk by the neoprene vest. This effect was relatively similar while paddling both a shortboard and longboard, but appeared to have a greater influence on trunk motion and erector spinae muscle activity when a larger surfboard was used.

These data provide a possible mechanistic explanation for the anecdotal reports of reduced pain from users of this product. Several pieces of evidence support the idea that reduced activity of back extensor muscles, particularly erector spinae, is associated with less pain both during and after a period of physical activity.[13,14,19,21] While the current data suggest that the inflation of the vest is important to realize these changes in muscle activation, it remains unclear how the inflated bladder acts to achieve this effect. One explanation might be that the bladder simply provides additional sensory feedback regarding the proper amount of back extension, and this point of reference then leads to more efficient control of trunk motion. Alterations in sensory feedback have been implicated in the control of the paddling motion previously.[24] The more likely explanation, however, is that the inflated vest may provide mechanical support for the upper torso and the surfer may allow their trunk to rest upon the bladder, thereby reducing muscle activation. The reduction in muscle activity in erector spinae observed here would therefore be the result of increased passive extension of the spine, caused by the inflated bladder, which may alter compressive forces and moments about the lumbar spine. Both of these proposed explanations are primarily speculative at this point. Additional study will be needed to further clarify the mechanism of action for the inflated bladder, and may lead to improvements in vest design.

It is also unclear whether the long-term effects of this reduction in muscle activity are beneficial for the paddling surfer. In particular, several investigators have provided evidence regarding the importance of isometric endurance of postural stabilizer muscles in the causes and management of chronic low back pain.[25–27] Since erector spinae activity is reduced while wearing an inflatable vest, it is possible that a reduction in muscle activity over many surfing sessions may result in a decrease in muscular endurance. However, the current data suggest that the erector spinae is still relatively active during prone paddling, even when an inflated vest is worn. While it is true that a statistically significant reduction in muscle activity was noted here, this decrease does not appear to be of sufficient magnitude to lead to a reduction in muscle endurance. Previous researchers have reported that muscle activation of only 30% of maximal voluntary contraction is sufficient to maintain lumbar stability and improve muscle endurance.[28] Therefore, additional study of the long-term effects of wearing an inflatable vest is also warranted.

While results for shortboard and longboard performance were relatively similar in the current data, there are mechanical differences between paddling boards of different size that may lead to differences in trunk kinematics and muscle activation. In particular, a board with greater volume is more stable and maintains a lower pitch angle when compared to a smaller board.[29] Because a larger board does not allow as much rotation in the sagittal plane of the paddling surfer, the athlete may respond with greater levels of back and neck extension while paddling. It is therefore not surprising that the inflatable vest had a greater effect on trunk kinematics during longboard paddling (18%, $P = .039$) when compared to paddling the shortboard (4%, $P = .320$) in the current data. Similarly, erector spinae activity was significantly reduced for the longboard condition but not for the shortboard condition. Since older adults tend to self-select larger boards[3] and are more likely to sustain a chronic injury related to surfing,[9] an inflatable vest might be particularly useful in this population.

Differences in muscle activation and trunk angle observed here appear to correlate with anecdotal reports of reduced low back pain from users of this vest. However, these statistically significant changes may not be physiologically relevant, and other explanations for reduced low back pain cannot be excluded on the basis of these results. For example, changes in the neuromuscular control of trunk stabilizing muscles have been implicated in low back pain and may be at least partially responsible for discomfort experienced by surfers.[30–33] In particular, increased delay in the onset of muscle activation in response to perturbation,[30,32] as well as changes in reflex activity,[30,31] lumbar stiffness,[32–34] and local dynamic stability,[34] have all been associated with low back pain. These variables may be very important during sudden perturbations that might occur during impact with a wave or while riding a surfboard on a dynamic and unstable surface. The current analysis did not account for other mechanisms that might contribute to low back pain in surfers, and it should be noted that the Ergo Vest may have protective and beneficial effects that were not examined here. Additional study of other surfing-related activities (eg, wave riding, duck-diving) and other potential mechanisms of low back pain are necessary to conclusively identify the primary factors that contribute to low back pain in this population.

There were a number of limitations to the current study that should be considered in the interpretation of these data. First, the swim flume did not fully represent paddling in the ocean, where water conditions are considerably less stable and surfers paddle at multiple velocities. Future analyses should consider the effects of paddling speed on muscle activation and low back and shoulder pain, and whether interventions such as the Ergo Vest might have a disproportionate effect at different speeds. Second, evaluation of muscle activity was limited to areas of the body that extend above the water due to limitations in instrumentation. Evaluation of other muscles and aspects of trunk motion can provide a more detailed picture of the effects of the Ergo Vest. Third, testing of different board types required that subjects return on a separate day. While some of the variability was limited by using the same subjects and following well-defined placement guidelines, placement of EMG electrodes can vary considerably between sessions thereby precluding any direct comparison between sessions. Combining an analysis of multiple boards within the same session would have been preferable. Finally, the average size of surfers in this study varied (mass: 74.7 ± 5.4 kg), requiring the use of different sized vests. Since all participants paddled the same board, it is likely that bouyancy varied across subjects and may have affected board and trunk angle, particularly for the shortboard trials. It is therefore possible that wearing this vest may differentially affect surfers of different sizes. This possibility was not controlled for in the current experiment, but could be investigated further in the future.

It is worthwhile to note that these data were acquired from surfers while paddling in water. There is currently a paucity of information available for muscle activation in water-based activities, likely due to the potential interference of water with the acquisition of electrical signals and the possibility of damage to costly equipment. This study demonstrates that surface electromyographic signals can be acquired during a water-based activity by using waterproof bandages to create a local, dry environment for the sensor. This technique holds promise for future studies of a similar nature, perhaps even permitting data acquisition in the ocean.

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