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Research article

Electromyographic analysis on a windsurfing simulator

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Abstract
Recent technical innovations in windsurfing have been concentrated on the evolution of the sails and the board. It is only recently that manufacturers have become interested in the wishbones which have evolved becoming thinner and lighter than in the past. A group of six experienced windsurfers participated in an experiment on a land based windsurfing simulator. The goal of the study was to analyze the muscular force used for different techniques for holding onto the wishbone. The test consisted in recording the global electromyographic activity of several muscles on the forearm using surface electrodes. There were two different wind force conditions possible with the simulator: medium (15 kg) and strong (25 kg). Three different wishbone diameters were tested (28, 30 and 32 mm). Four different hand positions on the wishbone were analyzed: leading hand and/or following hand in pronation and/or supination. The electrical muscular activity obtained varied significantly ($p < 0.05$) depending on the type of grip and according to the diameter of the wishbone. The position with the two hands in supination on a wishbone of 28 mm in diameter was the most economical in muscular terms, notably the flexions of the forearm. The confirmation of the results should lead windsurfers to reconsider the positioning of the wishbone and the adapted posture to waste the least amount of energy possible.

Key words: Forearm, performance, windsurf.

Introduction

The practice of windsurfing in the early stages often means muscular pains, cramps or spasms. This also continues for experts who train intensively. These symptoms come mainly in the forearms. The forearm pains are often intolerable during navigation and often result in the person stopping the activity (Jablecki, 1999). Sometimes, certain athletes have a chronic pain syndrome in their forearms which is rare (Fontes et al., 2003; Kouvalchouk et al., 1993; Rodineau, 1998). They have surgery that tries to cut the fascia of the forearm to allow further development. As in other athletic activities (Bird and McCoy, 1983; Gainor, 1984) these recent medical and surgical practices are unfortunately rare, but still cause worry.

For a windsurfer, sharp muscular pain remains a concern, though this activity provokes few traumas or pathologies (Habal, 1986; Porcella et al., 1992; Schonle, 1988). In order to better evaluate the number of windsurfers suffering from such pain and the impact it has on their activity, a questionnaire was established in 2003. The results confirm the importance of myalgia in windsurfing on 26 windsurfers that compete at the regional level. This was already shown in a study done with 119 windsurfers in the North of France (questionnaire from September 1982 to July 1983), where muscular pathology was more prominent: 64% of the surfers suffered from cramps, 44% from myalgia, 52% from stiffness and 23% suffered with diverse muscular bruising. The scientific studies concerning windsurfing are far from numerous. Most of the studies concern traumas that occur during the practice of the sport (Gosheger et al., 2001; Madsen et al., 1986; Nathanson and Reinert, 1999; Petersen et al., 2003; Prymka et al., 1999; Rosenbaum and Dietz, 2002; Salvi et al., 1997). Others depending on the level of competition of the subjects analyze certain physiological efforts (Bachemont et al., 1984; Chamari et al., 2003; Ciuti et al., 1996; Vogiatzis et al., 2002). Some studies using electromyography (Dyson et al., 1996; Gheluwe et al., 1998; Guerrin, 1987; Meurgey, 1994) show that on the body of a windsurfer, two anatomical sections can be distinguished by the specific type of muscular activity: an upper section comprised of the upper extremities, the upper chest and trunk, and a lower section comprised of the two lower members. The upper group works in traction and looks for the best compromise for endurance – speed; the lower group allows the body to be supported by the board and find balance.

Currently in the windsurfing domain, technological research is mostly concentrated on the evolution of the sails and board; it has been only recently that manufacturers have become interested in wishbones, that have now become thinner and lighter than in years past. The cut has become more oval and the curve less obvious. However, these innovations are based on 'feeling' and the sensations of windsurfers with little scientific information and studies to back up these changes.

The goal of our study was first to elaborate and validate our land based windsurfing simulator recreating in the laboratory an environment and constraints on the windsurfer as close as possible to reality. Secondly, our objective was to reveal the influence of the hand position on the activity of the anterior muscular areas of the forearm.

Methods

Six right-handed male windsurfers, competitors at the regional level, participated in the study. The subjects' average (±SD) age, height and weight were 22.4 (±2.7) years, 1.74 (±0.9) m, and 68.9 (±7.5) kg, respectively. Participant selection criteria included the absence of previous neuromuscular or musculoskeletal disorders related to the upper members. After being informed of the pur-

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pose and possible risks of this study, written informed consent was obtained from each subject. (Figure 1)

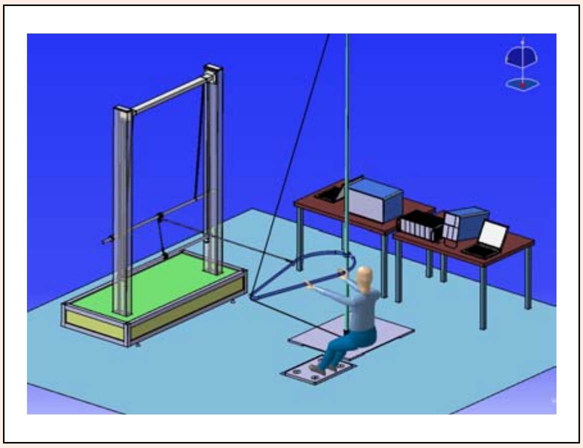

Figure 1. A diagram representing the land based windsurfing simulator using the CATIA V5 software allowing the simulation of the windsurfer in action. The system is comprised of several elements : an electronic weightlifting bar fixing the constraining weight applied to the wishbone by a steel cable ; the electromyographic analysis system ; a fixed base for the mat.

This is comprised of a limited zone on the ground measuring 60 cm by 40 cm where the subject places his or her feet. The rigging is done with a section of a mast measuring 3.5 m and a wishbone attached by a cord simulating the tension produced by the sail. The wind force is represented by a traction force on the wishbone. The system requires the use of an electronic weightlifting crossbeam such as a Bérénice (Verdera, 1999).

This apparatus can replace traditional equipment (iron mast, free bar…) by the use of a bar attached to oscillating pillars controlled by an electric motor. This allows the execution of all types of movements, thus all types of muscular contractions (isometric, anisometric and pliometric), with a well defined mechanical constraint. The electrical motor follows a program in order to standardize the effort imposed on the athlete. The motor function is controlled by the laws of electromagnetism thus does not rely on external factors. A control box allows the regulation of different parameters that change the force of ascension and descent, and a reference position for the bar (the released bar comes back automatically to the reference position). The crossbeam is used isometrically which means the subject must fight to not follow the movement the bar imposes.

A recording system for the global electromyographic activity is used to measure the muscular activity of the forearms and more precisely the superficial flexors in the fingers. Six tracks were used; three on each arm (Figure 2). To receive a quality signal, the skin must be prepared, then place the electrodes and regulate the amplification (gain) of the apparatus. The global electromyographic activities are detected by a bipolar derivation with the help of a surface electrode such as a Beckman, with a diameter of 8 mm. They are comprised of a plastic surface that contains a block of silver chloride (Ag/AgCl). An electrolytic gel is used to insure the contact between the electrode and the skin. The distance between electrodes is 2 cm and the electrodes are placed on the skin with double-sided adhesives following the direction of the muscle fibers. Exfoliation of the top layer of skin is performed using an abrasive material. The oil on the skin is removed before placing the electrodes using a mixture of alcohol and ether in order to decrease the electric resistance of the skin. The signals obtained are amplified by the measurement instrument at a frequency between 20 Hz and 1000 Hz. The electromyographic signals are visualized with the help of a cathodic oscilloscope that allows the experimenter to control them.

Several adjustments must be made to the recordings on the simulator to adapt to the characteristics of each subject. 1) The first adjustments are those of the rigging: the subject adjusts the height of the wishbone to their liking. The distance between the force platform and the base of the mast is standardized (we use the measurements obtained with a floater like those of Formula: width (100 cm) and distance from the foot of the mast to the mid point between the foot straps (78 cm), and the foot of the mast is placed 50 cm in front of and 78 cm to the side of the center of the limited zone. 2) Then, the subject mounts the platform to get used to the simulator. The subject performs some pumping actions (the Bérénice does not apply any more force than the bar's mass). We then ask the subject to get into position as if navigating in side winds (the force given by the Bérénice is perpendicular to the wishbone), and to move the Bérénice bar in order to find a position where they feel balanced and stable. Then we place a mark on the Bérénice frame for their bar placement. 3) Another mark is placed on the first third of the wishbone which corresponds to the projection of the center of the sail area push on the wishbone. The subject must position their hands according to this mark.

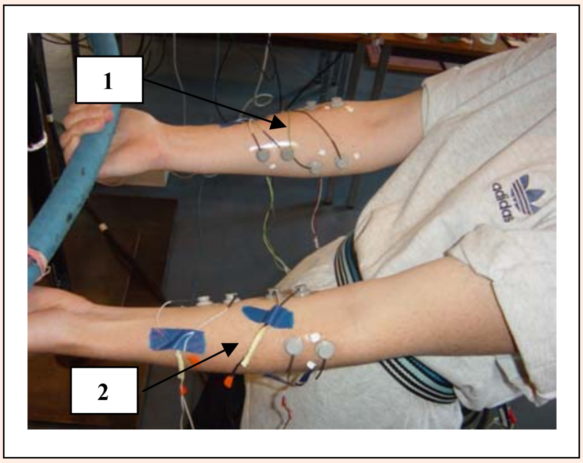

Figure 2. Positioning of the electrodes on the forearm of the leading hand (1) and the following hand (2).

After a specific individualized warm-up, the subject gets on the land based windsurfing simulator. The starting position is the following: the subject places themselves in the limited zone where they grab the rigging positioning with their leading hand holding the wishbone, the following hand is just laying on the wishbone ready to resist the forces the will be put onto it. They must take the sail by pulling on the leading hand so that the cable attaching the wishbone to the frame of the Bérénice makes a 90° angle with the wishbone. The subject finds themselves at a side wind speed so as to place the Bérénice bar at the level marked before**.** The subject does not resist any force other than the rigging weight; their arms and legs are extended. They must hold the cable attaching the wishbone to the frame of the Bérénice while holding the rigging and resisting the forces applied by the Bérénice. Once in this position, the recording starts for the electromyographic forces and the Bérénice.

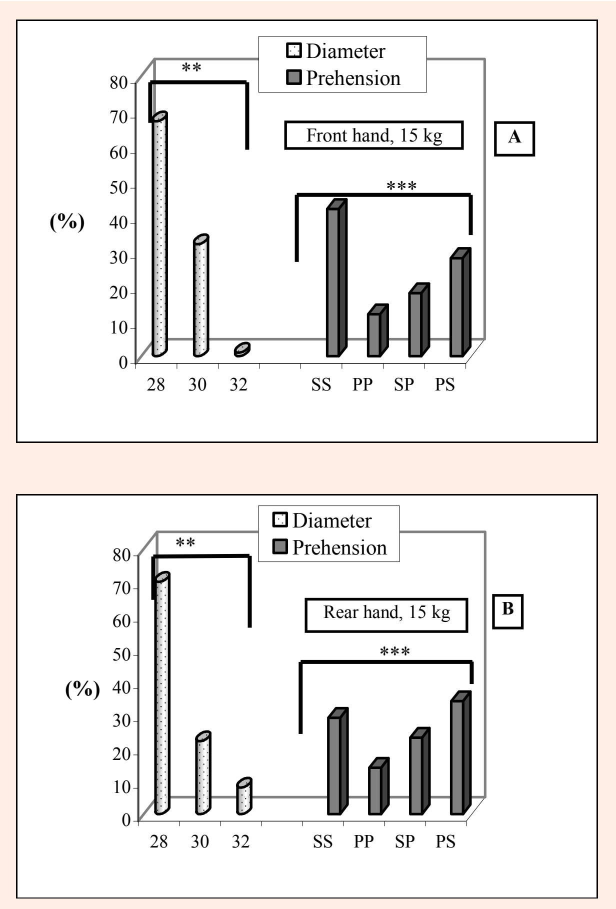

Figure 3. Results of the electromyography depending on the use of 15 kg for the forearm and the leading hand (A) and the forearm of the following hand (B). The values where the muscular activity is at minimum are represented in a percentage (%) depending on: the diameters of the wishbone (28 mm, 30 mm, 32 mm), the position of the hands (leading, following) in pronation (P) or in supination (S), in order to test the four postures (SS, PP, SP, PS).

Each subject does a total of 6 runs lasting 2 minutes each. In fact, the runs are done with the three different wishbone diameters (28, 30 and 32 mm) that were chosen thanks to a study performed in situation with 26 windsurfers and two different constraining weights (15 and 25 kg) representing medium and strong wind forces. The subject must perform the exercise with the three different wishbone diameters and the two different masses. During each run, the subject must perform each of the four hand positions in random order: the two hands in supination, the two hands in pronation, one hand in each pronation and supination. They change hand positions every 15 seconds. Estimating the time needed to change positions at 5 seconds, the track lasts 75 seconds plus the time to raise the bar to the marked position for maximum of 2 minutes.

While on the simulator, the subject must keep the same positions studied for fifteen seconds. The data analysis is based on the 5 seconds in the middle of the 15 seconds for each of the four positions. The data recorded by an analogical/digital card (Computer Boards , PCM-DAS16D/16) with a frequency of 1000 Hz were analyzed according to the protocol of Meurgey (1994). Graphs represent the integrated electrical muscular activity over time. We then analyzed the lines obtained in order to show the diameter and hand position which correspond to the weakest electrical activity. This study was done in two steps: 1) First, we compared the lines obtained for the four hand positions for one wishbone diameter at one constraining force given for each of the six runs. At the end of this first comparison, we underlined for each run the hand position where the electrical activity is the weakest. 2) Secondly, we compared these hand positions found with each wishbone diameter.

All data was entered into SPSS 10.1 for Windows. The results were presented as mean ± standard deviation (±SD). We tested the influence of the diameter of the wishbone (28 mm, 30 mm, 32 mm) on the fatigue of the forearm depending which hand was leading or following no matter the constraining weight (15 kg or 25 kg) by using Friedman's non parametric tests for several samples linked in pairs with the Wilcoxon test. The same was done to judge the effect of the gripping technique used in front or in back (PP, SS, SP, PS) on the fatigue of the forearms whatever the diameter used or the constraining weight used for the same tests. Statistical significance was accepted at $p < 0.05$.

Results

The significant results using Friedman's tests show that there are important differences in the electromyographic values in the forearms, leading hands and following hands depending on the diameter of the wishbone or the gripping technique used whatever the constraining weight used (15 kg or 25 kg).

In Figure 3A one can see that 68% of the subjects used their forearms minimally ($p < 0.01$) when they use a wishbone of 28 mm in diameter. This is true for only 32% of those using one of 30mm in diameter and 1% for 32 mm in diameter. The technique used which is the least strenuous at 42% of the subjects ($p < 0.001$) was when both hands were in supination (SS). The other preferred technique at 28% was with the leading hand in pronation and the following hand in supination (PS).

Figure 3B shows the results of the forearms of the following hand with the initial position with the hand in front. This was interesting for the use of the 28 mm diameter and for two techniques (SS) and (PS). The difference was less dominant with percentages at 29% and 34% respectively for a wind force considered weak.

The increase of the constraining weight by 10 kg did not emphasize the results found using only 15 kg, actually the contrary was true (Figure 4A and 4B). For the forearm of the leading hand as well as the following hand, the differences between hand position techniques decreased even though the results of Friedman's test revealed a significant difference in the sample group ($p < 0.01$). The preference for the 28 mm diameter was again predominant for 59% of the leading hands and 67% for the following hands.

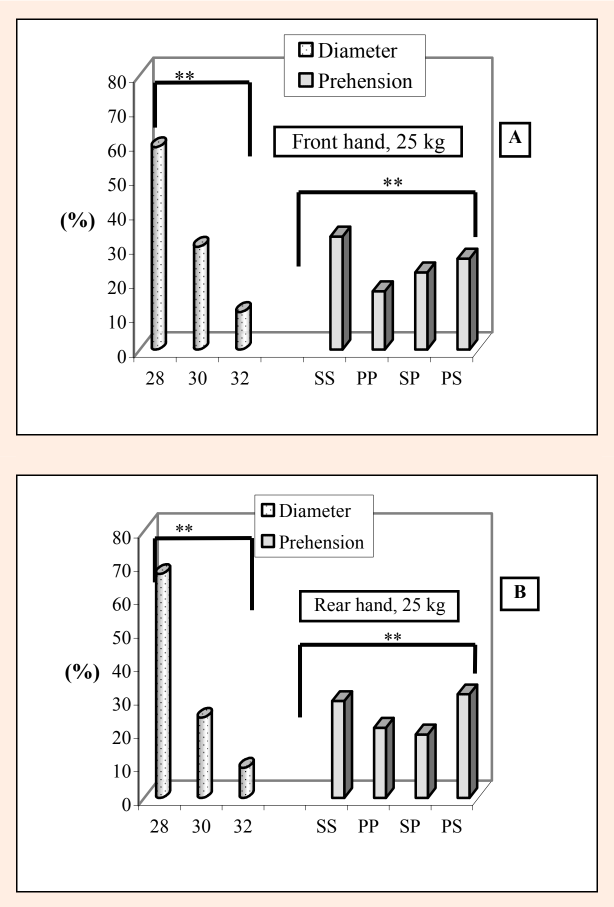

Figure 4. Results of the electromyography depending on the use of 25 kg for the forearm and the leading hand (A) and the forearm of the following hand (B). The values where the muscular activity is at minimum are represented in a percentage (%) depending on: the diameters of the wishbone (28 mm, 30 mm, 32 mm), the position of the hands (leading, following) in pronation (P) or in supination (S), in order to test the four postures (SS, PP, SP, PS).

Discussion

Windsurfing is a sport that can begin during early childhood because it is above all an activity of balance that does not require extreme effort or resistance. This is why manufacturers make boards that evolve with the child that are smaller and lighter with a smaller sail adapted to less developed muscular structures. However, a questionnaire done before the study revealed several characteristics of windsurfing including pain felt during and after the activity. It appears that a large majority of people practicing this sport suffer from muscular pain. In fact, 65% of the people questioned have muscular pain while windsurfing and 70% after the activity, for the most part in the forearms. Concerning the equipment used, we noted that 60% of the athletes questioned use a wishbone 30 mm in diameter. However, it seems that the forearm pain decreases with the use of a thinner wishbone. Furthermore, we noted that the grip positions on the wishbone the most frequently used are two hands in pronation (68 % of windsurfers questioned) and also the leading hand in pronation and the following hand in supination. Considering all the information, the goal of this approach was to study certain factors that can influence the appearance of forearm pain.

Several studies addressing technical ergonomy and muscular fatigue (Gheluwe, 1988) brought forth using notably electromyographic analysis the idea that the upper muscular groups were much more active than those of the lower body (Guerrin et al., 1987). Also tests concerning the anterior areas of the forearm varying the constraining weights show even if it is not perfectly linear an excellent proportionality. Certain electromyographic data taken in navigation sequences without 'pumping' recorded and calculated almost correspond to those of isometric conditions. The comparative studies on hand positions allowed us to come up with a diagram of specific hand placement that saves energy where the leading arm is outstretched and the following arm is bent, with both palms turned upwards in supination (SS). It was shown that for all the positions performed by the windsurfer, the developed strength values of the anterior muscular areas of the forearms were systematically weaker with the hands in pronation than in supination (Meurgey, 1994). Moreover, it also seems that whatever the activity or the discipline of windsurfing that the finger flexor activity is very important (Dyson, 1996).

Concerning the present electromyographic study, for a constraining force of 15 kg, the grips on the wishbone that require the least amount of muscular activity are: both hands in supination (SS) and the leading hand in pronation and the following hand in supination (PS). Such a position is obviously impossible to perform. We note however that both hands in supination allows one to perform weak muscular activity in almost as many cases as when the following hand is in supination and the leading hand is in pronation. Among the positions that are possible to perform, the position using the least amount of energy is both hands in supination (Figure 5).

For a constraining force of 25 kg, the results concerning the weakest muscular activity of the forearm are similar to the results found with 15 kg, finding again with both hands in supination. For the following hand, we obtained the same sort of results, notably that the two positions appear with frequencies almost equal: both hands in supination (29%) the following hand in supination and the leading hand in pronation (31%). We also see that with both hands in pronation appears in 21% of the cases seen. We can thus question if a position with the leading hand in pronation makes it easier on the following hand.

The study of the hand positions underlines the fact the position that uses the least amount of muscular activity is both hands in supination (SS). Yet this is not the position used most frequently by windsurfers according to the 26 questioned who prefer both hands in pronation

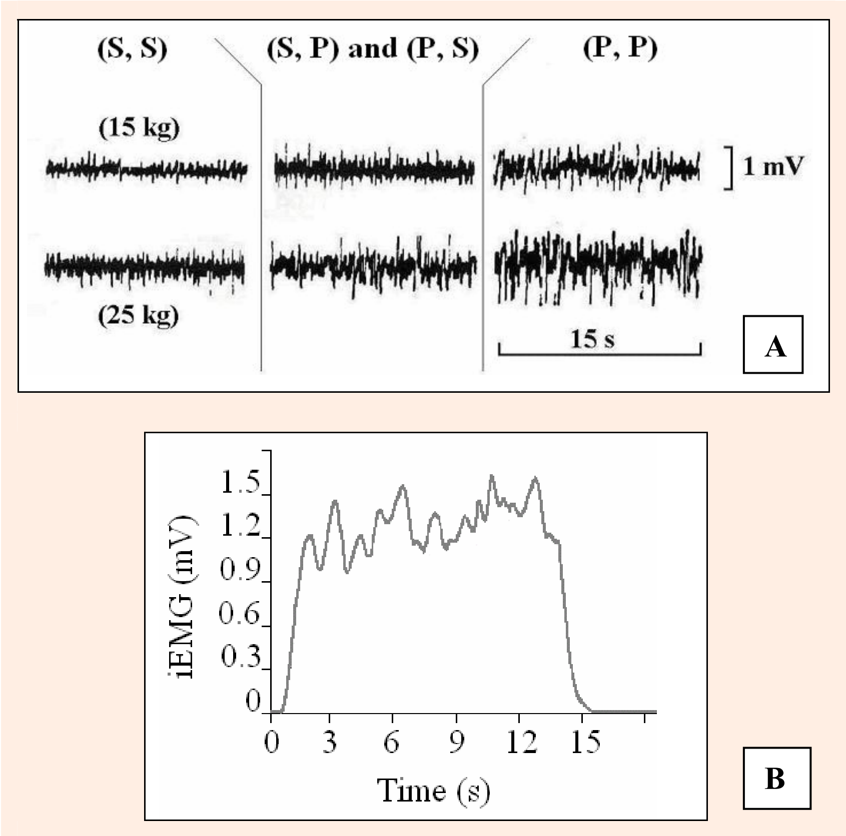

Figure 5. Example of a raw EMG signal (A) recorded and integrated EMG (B) on the muscles of the forearm when the subject's hands are in different positions (SS; SP, PS; PP) holding the wishbone still, loaded at 15 kg or 25 kg.

(PP). We can also note that the study was performed without the use of a harness though in the reality of the sport, it is a must. In fact, it relieves the lower back muscles as well as those of the upper members. However, efficient use of a harness requires the person to be accustomed to its use and good sail adjustment is not done by pulling the wishbone, rather pushing it. The efforts are thus not the same.

Three diameters of wishbones were chosen based on the sizes available on the market for windsurfing. The electromyographic study shows indisputably ($p<0.01$) that no matter the constraining weight used on the wishbone, the hand positions and the forearm studied, muscular activity is at its weakest using the smallest diameter tested, 28 mm.

It would be advised, given the initial goal of association in parallel to the study of the factors studied, others more physiological, anthropological and postural in order to obtain an optimal size for the wishbone specifically for athletes. As we have indicated in windsurfing, fatigue is felt first in the forearms. This brings on cramps that effect beginners as well as experienced surfers. There is nervous fatigue in the motor end-plate with the decreasing level of acetylcholine released but also the decreasing level of acetylcholine esterase which brings the possibility of blocking the forearm by a residual amount of acetylcholine. Also, the forearm and finger muscles work statically. Since they remain tense to hold onto the wishbone, the capillaries stay closed decreasing the blood flow, increasing lactic acid production, pain and cramps because the muscles have not worked aerobically. In the same way as the finger flexors work in synergy with the wrist extenders, the more the wrist is extended more the stronger the flexors. Therefore, to have the same results in holding the wishbone, the static strength required from the flexors decreases and the cramps are delayed if the wrist is slightly extended. Ideally, the wrist should be extended to around 15°.

This study addressed two performance conditions for windsurfing, notably that which concerns the limiting factor 'muscular pain of the forearms': the diameter of the wishbone and the hand position used by the windsurfer. Confirming the economic position of both hands in supination on the wishbone, the study provides useful information to windsurfers, allowing them to navigate without their activity being limited by muscular pain in their forearms. The study of the wishbones different diameters, which allowed us to determine an optimal diameter of 28mm, will be of great interest for those practicing the sport as well as manufacturers and designers of the equipment finding information to help or confirming their innovations. However, one important limit to this study is that it represents the work done on a land based simulator that does not replace the variability of natural wind conditions affecting the sail or the effect of the waves on the balance strategies of the windsurfer. We used the basic positions of a windsurfer from a static point of view. Obviously on the water, the subject is constantly changing positions to reach balance regulating the sail according to the wind strength, which is not the case here.

Conclusion

The important activity of the flexor muscles in the fingers in windsurfing compared to other muscle group activity is thus clearly established; it now seems it could be interesting to study this activity to reveal the positions in which it is the strongest. Our study confirms the results of previous studies by showing the flexor muscle activity in the fingers is stronger when the hand is in pronation. This would explain the pain felt by most windsurfers in their forearms. These pains are linked to an accumulation of lactic acid associated with weak localized oxygenation. To hold off the presence of these pains and fatigue, the surfer frequently changes hand positions (palm up or down). This intermittent change improves the quality of vascular circulation. To rest, the windsurfer can also hold the wishbone in the crook of their arm or with the armpit of the following arm, but there is a risk of nerve and vascular compression and this position cannot be held very long. The use of a wishbone which is small in diameter (28 mm) seems to decrease the muscular activity of the flexors in the fingers, and thus using this type of wishbone can avoid muscular pain in the forearm for as long as possible.

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Key points

- The study was to analyze the muscular force used for different techniques for holding onto the wishbone.
- Three different wishbone diameters and four different hand position were tested.
- The position with the two hands in supination on a wishbone of 28mm in diameter was the most economical in muscular terms.

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