ANALYSIS OF DYNAMIC TRAPEZE SAILING TECHNIQUES

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The purpose of this study was to simulate dynamic trapeze sailing to determine the stress placed on the musculoskeletal system. Muscle activations from the erector spinae and external oblique musculature were measured using electromyography and combined with joint kinematics to analyse several dynamic trapeze sailing postures. Dynamic trapeze sailing involved stresses to the musculoskeletal system that previous studies failed to indicate. These stresses included constant use of external oblique and erector spinae musculature to stabilise the trunk, rapid extension/rotation of the trunk coupled with eccentric muscle contraction during dynamic body pumping techniques, and increases in muscle activations owing to asymmetrical body positions. These results have implications for trapeze harness design and injury prevention.

KEY WORDS: sailing, electromyography.

INTRODUCTION: Trapeze sailing is a technique used by certain classes of dinghies (including the Tornado, 49er, and 470 Olympic class) to maintain the boat in an upright position, thereby maximising performance. A trapeze harness is worn, allowing the sailor to be attached to a wire on the mast via a metal hook and hang off the edge of the boat, effectively increasing the moment arm to counter the moment generated by the wind on the sails (see Figure 1). Anecdotal evidence of low back pain amongst trapeze sailors is well recognised in the sailing community, however there is a paucity of research in the area.

Marchetti et al. (1980) investigated the cardiovascular and muscular stress associated with trapeze sailing in a laboratory environment and concluded that trapezing was a light exercise that placed little stress on the cardiovascular and musculoskeletal system. This study was limited to static postures only, which did not accurately simulate trapeze sailing on-water.

A more recent study conducted by Hall et al. (1989) investigated various trapeze harness designs using electromyographic (EMG) data as an indication of muscle stress. Certain harness designs were effective in reducing the activations in the erector spinae and external oblique musculature, however results from this studywere again delimited to static postures.

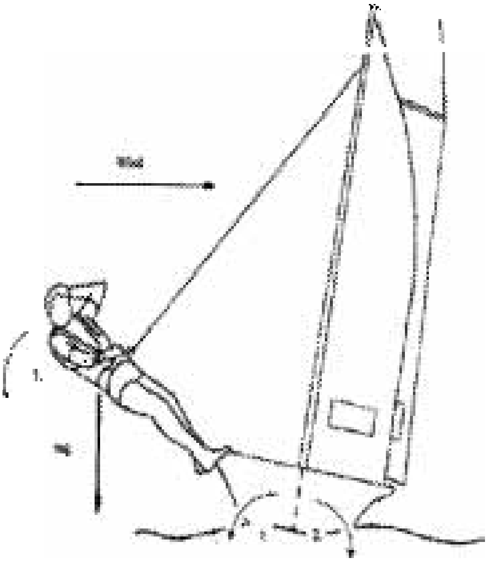

Figure 1 - The forces acting to rotate the boat during trapeze sailing include:

1. gravity acting through the sailors centre of mass,
2. force acting on the sail from the wind, and
3. force due to the acceleration of the body during body pumping.

Trapezing techniques have become more dynamic in recent years and include various body movements such as 'body pumping'. This involves a rapid flexion-extension movement of the spine that is believed to improve boat speed by; (a) pushing the boat through the back of a wave, thus enabling the boat to 'ride' the wave, and (b) 'pumping' the sail in an effort to increase laminar flow and promote lift.

The purpose of this study was to analyse dynamic on-water trapeze sailing and replicate these movements in a controlled setting to better understand the stresses placed on the musculoskeletal system.

METHOD: Two National level male 470-class sailors (S1 and S2) participated in the study. Heights for S1 and S2 were 1.63 and 1.69 m respectively, while weights for S1 and S2 were 78.1 and 64.3 kg.

Experimental Design: Subjects were filmed 'on-water' to determine the angles of the mast and boat to horizontal during wind strengths of 5 to 20 knots. These angles were calculated using a Peak Motion Analysis System and were used to replicate the boat positions in the laboratory. Sagittal trunk and knee angles were also calculated during these wind strengths to determine the range of motion and body positions to be replicated in the lab. The trunk angle was defined as the shoulder-to-hip segment in relation to the thigh.

A trapeze simulation of a 470 dinghy was constructed in the laboratory by suspending a trapeze wire from a mast of 3 inch steel scaffolding pipe. Similar pipes were used to construct the side of the dinghy so that the sailor could 'hook-in' to the wire and lean against the scaffolding as they would on a 470 dinghy, using the 'on-water' boat angles to replicate the simulation position.

Subjects were required to become familiar with the testing apparatus before data collection. Each sailor then performed five different tasks, chosen from the on-water analysis and performed in a random order. These tasks were designed to replicate:

1. Light wind sailing
2. Moderate wind sailing
3. Strong wind sailing
4. Body pumping with both arms by the side
5. Body pumping with one hand above the head

Each task was repeated five times with a 10-minute interval between trials to reduce fatigue.

Data Collection and Analysis: Bipolar EMG electrodes were placed on the erector spinae muscles at positions 3 cm to the right of the T5 vertebra (T5) and 3 cm on both sides of the L4 vertebrae (L4), as well as 3 cm superior and anterior to the iliac crest over both extemal oblique muscles. Electrode sites were chosen to replicate the method used by Hall et al. (1989) in their static trapeze study.

Prior to testing, subjects performed maximum isometric muscle contractions for each muscle group to normalise the EMG data. Raw EMG data were recorded for 10 s during each trial on a Macintosh computer using Chart v3.3 (AD Instruments Ltd.), and were then full-wave rectified and filtered using an in-built moving average algorithm in Scope v3.3 (AD Instruments Ltd.). Mean values of the filtered and normalised EMG data were used in an ANOVA to test for significant differences between tasks and asymmetrical muscle activity.

Two video cameras were used to collect three-dimensional kinematic data during these tasks using a Peak Motion Analysis System. Sagittal plane trunk, hip, and knee angles were measured as well as angular velocities and accelerations of the trunk segment during body pumping. These data were averaged across trials and compared using a one-way ANOVA.

RESULTS AND DISCUSSION: The main difference between measurement on-water compared to that in the laboratory simulation was the range of motion of trunk and knee angles. Standard deviations (SD) of trunk and knee flexion/extension angles measured on-water were consistently greater than in those measured in the lab. For the moderate and strong wind sailing tasks, mean trunk angle SD was 10.0" on-water compared to 0.8° in the lab, with similar results for the knee. The lab simulation could not emulate the subtle changes in wind strength and water conditions, so care must be taken when drawing implications from any static postures performed in a controlled environment. Body pumping movements and light wind sailing however, were better replicated in the lab simulation.

During light winds, the sailor crouched inside the boat with large flexion at the knee, hip, and trunk in order to stay close to the axis of rotation of the boat whilst attached to the trapeze wire. If the wind remained light, this flexed position would be maintained for the duration of the race. When replicated in the lab, the light wind sailing posture elicited high muscle activations (%MVC) from the erector spinae at T5 and extemal oblique muscles (35–40% MVC respectively). These activations were significantly greater ($p<0.05$) than the static moderate and strong wind sailing tasks, which would suggest that light wind trapeze sailing could be just as demanding on the muscles stabilising the trunk as sailing in stronger winds. The trapeze harness is not designed to support the sailor whilst they remain in the boat, therefore the sailor must rely more on muscles to provide support in this position.

As wind speed increased, trunk and knee extension also increased as a response to maintain the righting moment and keep the sail surface area perpendicular to the wind. Muscle activations measured during these two conditions were similar for both sailors and reasonable small in magnitude (–20% MVC) compared to the dynamic tasks performed. These activations are likely to be underestimated due to the static nature of the laboratory simulation, yet it should be noted that even during these static postures, the muscles stabilising the trunk were still active. Hall et al. (1989) showed that different trapeze harness designs could reduce the muscle activations during static trapeze sailing postures, however further research is required by harness manufacturers to better understand the requirements during on-water sailing in a variety of wind strengths. Changes to trapeze harness design were outside the scope of the present study.

The body pumping movements in the lab were believed to be an accurate representation of what actually occurred on-water in terms of kinematics. Trunk flexion/extension was consistent for both sailors, ranging from -1° to 8° of flexion for S1 and -2° to 13° for S2. The range of motion was not a concern in terms of injury potential to the spine, however the rapid changes in speed at which the flexion/extension occurred may increase the risk of injury to the musculoskeletal system. Accelerations for flexion and extension were similar in magnitude, with an average of 580 deg.sec^{-2} for both sailors and peaks of up to –1000 deg.sec^{-2} common. Marras and Mirka (1992) found that muscle loading is expected to be greater in dynamic tasks to counter the inertial forces produced by accelerating the trunk. The added muscle force throughout a range of external loads and velocities may be quite small yet, owing to the muscles small moment arms, the effects of these increases in spine loading could be significant in producing low back pain (Marras and Mirka, 1992). Eccentric contractions used to decelerate the spine may also play a role in the development of muscular pain during trapeze sailing.

Fatigue from dynamic body pumping movements may also be cause for concern considering the need to stabilise the spine over a long period of time (up to 20 minutes per race). Bigland-Ritchie (1981) found that repeated extension and flexion of the trunk lead to localised muscular fatigue, reducing the capacity to perform work. This would have an impact on the muscles' ability to stabilise the spine (Seidel et al., 1986; Seidel et al., 1987).

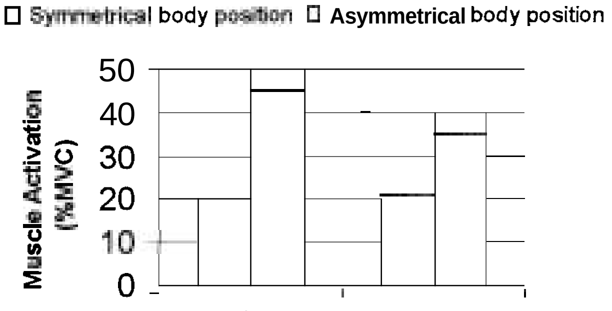

Figure 2 - Muscle activations for the lumbar section of erector spinae during body pumping with hands by the side (symmetrical position) and with one hand above the head (asymmetrical).

Peaks in the filtered EMG signal were clearly visible for the external oblique and L4 erector spinae muscle sites corresponding to trunk flexion and extension respectively. If body pumping movements lead to a rapid onset of fatigue, the muscle's ability to protect the spine and maintain a correct trapezing posture would be greatly reduced.

A technique used to counter an increase in wind strength was to place one hand above the head, effectively shifting the sailors mass away from the axis of rotation. This body position also caused a rotation of the shoulders in relation to the hips due to the added mass away from the midline of the trunk. During dynamic body pumping movements, this shoulder rotation was accentuated and found to be ± 10 degrees relative to the hips. A significant increase in all muscle activations ($p<0.05$) occurred during body pumping movements with an asymmetrical body position. The increase in activations on both sides of the spine during extension-rotation movements indicated that co-contraction of lateral muscles may be used to stabilise the trunk and prevent excessive rotation of the spine. A downward rotation of the right shoulder also resulted in increased activations from the left side of erector spinae and external oblique muscles compared to the right ($p<0.05$). These individual muscle activations may be a result of type Ia muscle stretch reflexes, used to counter rapid movements of the trunk and maintain joint integrity. The implications of asymmetrical muscle activations range from increased risk of over-exertion to increased loading on the spine (Marras and Mirka, 1992).

CONCLUSION: Dynamic trapeze sailing involves stresses to the musculoskeletal system that previous studies have failed to indicate. These stresses include constant use of external oblique and erector spinae musculature to stabilise the trunk, combined extension/rotation of the trunk, and increases in muscle activations owing to asymmetrical body positions.

Trapeze harness designs need to support the body in light wind sailing postures, as muscle activations required to stabilise the trunk during these conditions were just as high as the strong wind sailing postures. Sailing in light winds for the duration of a race would increase the chance of muscle fatigue and soreness.

Body pumping movements involved large accelerations of the trunk, coupled with eccentric muscular contractions that may increase the risk of developing low back pain through increased loading on muscles and increasing the onset of fatigue to muscles that stabilise the spine. Techniques used in stronger winds such as body pumping with one arm raised behind the head should be avoided due to combined extension/rotation of the trunk, increases in overall muscle activations, and asymmetrical muscle loading.

The merits of performing body pumping techniques in trapeze sailing have to be questioned when considering the anecdotal 'advantages' in boat speed with the increased stress to the musculoskeletal system and potential for injury. Alternative techniques such as using the legs to drive the dinghy through the water should be considered and investigated.

REFERENCES:

Bigland-Ritchie, B. (1981). EMG/force relations and fatigue of human voluntary contractions. *Exercise and Sport Science Reviews,* **9,** 75-117.

Hall, S., Kent, J., & Dickinson, V. (1989). Comparative assessment of novel sailing trapeze harness designs. *Infemafional Journal of Sports Biomechanics,* **5,** 289-296.

Marchetti, M., Figura, F. & Ricci, B. (1980). Biomechanics of two fundamental sailing postures. *Journal of Sports Medicine,* **20,** 325-331.

Marras, W. S. & Mirka, G. A. (1992). A comprehensive evaluation of trunk response to asymmetric trunk motion. *Spine,* **17,** 318-326.

Seidel, H., Bluethner, R. & Hinz, B. (1986). Effects of sinusoidal whole-body vibrations on the lumbar spine: the stress-strain relationship. *Inf Arch Occup Environ Health,* **57,** 207-223.

Seidel, **H.,** Beyer, H. & Brauer, D. (1987). Electromyographic evaluation of back muscle fatigue with repeated sustained contractions of different strengths. *European Joumal of Applied Physiology,* **56,** 592-602.

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