Improving comfort while hiking in a sailing boat

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Abstract

The paper presents the changes in perceived comfort while hiking in a sailing boat (in this case the Laser, a single-handed Olympic dinghy) due to a new design of hiking pads. The project used a ‘research by design method’. The aim was to improve sailing comfort which leads to lower fatigue and therefor improved performance. While hiking, a large force is exerted on the thigh of the sailor by the boat rim while existing hiking pads only partly distribute this force over the upper leg. In order to find directions for improvements we analyzed the interaction between upper leg and boat rim and forces involved, studied the anatomy of the upper leg and quantified the pressure distribution over the upper leg using an experimental set-up. A new hiking pad was designed and tests showed an improved pressure distribution over the upper leg. First field test showed positive results. The hiking pads will be made available to the Dutch Olympic Sailing Team in order to improve their competitiveness at the 2012 Olympics in Weymouth.

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1. Introduction

Hiking, balancing your upper body outside the boat while keeping your feet under a foot strap (see figure 1) in order to keep the boat upright, is a highly demanding activity for a sailor [1]. The physical stress of hiking has been documented well since Rogge’s work [2]. In conditions where wind speeds exceed 8 knots (4.1 ms⁻¹), 29 – 94% of sailing time is spent hiking in boats like the Laser (a 14-ft single-handed Olympic dinghy) [3]. The sailors’ performance while hiking is influenced by pressure on the thighs; veins are compressed, hindering the drainage of waste fluids (i.e. lactate) produced by the anaerobic activity of muscle such as the quadriceps. This mainly leads to muscular fatigue but also inner

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tissue damage and in the end overall discomfort. Elongated hiking also causes injuries in ankle, knee, thigh and hip/spine area [4]. A direct result of muscle fatigue is the search for new hiking positions. The hiker will deviate from the ideal (or least injuring) position, causing injuries in other muscle groups [5].

The Laser class -used as reference during this project- has large numbers of competitors; 23% of the participants in the 2012 Olympic sail races compete in this class. However, the design of the Laser boat rim is not optimized for hiking; it has a -rather unpleasant- 10 mm curvature. A logical solution for reducing the hiking discomfort - from a product design perspective- would be to alter the shape of the boat rim. Unfortunately, due to strict class regulations, changes in the hull are not allowed.

In order to overcome the large pressures caused by hiking, sailors already use various commercially available devices; separate hiking pads for placement inside the wet-suit or hiking pants with fixed pads. First analyses of these devices made us believe they could be optimized further in order to reduce hiking discomfort and improve the sailors overall performance.

![Fig. 1. Laser sailor hiking; feet below the hiking straps, left hand holds hiking stick (helm extension) right hand holds main sheet](image1)

![Fig. 2. Simplified representation of external forces acting on the sailor when hiking (forces exerted by the arms not included)](image2)

Literature provided us with data on standard postures of hikers, angles between body parts, body mass and stature [1, 4], these data have been used in a static model describing the forces on both the thigh and calf (see figure 2). Dimensions of the foot, lower leg and upper leg are average segment values for a 1m83 male subject (average for male sailors in the Laser Class[4]). The resulting forces acting on the subject have been converted into forces along the leg and perpendicular to the leg. It turns out that the calf is mostly suffering from the shear forces (739 N) and almost no forces directly into the leg (71 N). For the thigh this is different, both a high shear forces (1142 N) and normal force (1325 N) are applied. The magnitude of this force demonstrates the need to use hiking pads in the thigh area in order to distribute the force over a larger area and so reduce local high pressure.

2. Design of a new hiking pad

A research by design project was started in order to explore the improvement potential of hiking pads. The design project started by analyzing the user-product interaction; both desk research and interviews with sailors provided additional insight into the design challenge. It showed that the current hiking pads were experienced as being heavy and thick and not comfortable. Current pads inside the wet-suit cause a sudden change of thickness; this decreased the ability of the sailor to slide in and out of the boat easily.

The design efforts aimed at tuning the hiking pads to the characteristics of the upper leg; the area just above the knee is a tendous area with numerous nerves, ligaments and blood vessels and therefore rather
vulnerable. In contrast, the area near the buttock is characterized by large muscles and a higher fat percentage and therefore less vulnerable to high pressure.

The final design of the hiking pads consisted of three layers; a rigid midlayer distributing the impact force over a larger area, a comfort layer on the skin-side and a padding layer on the outside to absorb impact (see fig 3). Further design alterations consisted of thickness reduction, seam reduction, changes in overall geometry and longitudinal stiffness of the pads. Due to the fact that deformation of the legs’ skin highly depends on edge geometry [6], also the design of the edges was adapted. After several iterative design steps, first prototypes of the new design were made by adapting the current Magic Marine battenpads in order to allow for testing.

Fig. 3. Design sketches exploring ideas for stiff construction in combination with new materials (left) and proposed cross section of the new design (right)

3. Experimental set-up

Both the existing Magic Marine battenpads and the new pad design were tested. Purpose of the tests was to measure the differences in stress distribution (lab set-up) and reduction of perceived discomfort (user tests).

3.1. Laboratory tests

The experimental set-up consisted of a cylinder (125 mm diam.) representing the human upper leg. Due to restrictions in the load capability of the pressure mat, the cylinder was filled with solid material up to a total weight of 2.9 kg. The cylinder was covered with foam in order to mimic the average behaviour of skin, fat layers and muscles of the upper leg. The test set-up did not mimic the variation in knee-side vs. buttock side characteristics of the upper leg. Pressure distribution was measured with a pressure mat (mFLEX® type ACC2), taped to the cylinder. The boat rim was represented by a piece of MDF, shaped like the Laser boat rim. The cylinder and MDF were placed perpendicular to each other (see figures 4 and 5). The hiking pads were mounted between the pressure mat and the MDF rim.
3.2. Field test

Both the existing Magic Marine battenpads and new design were used in a qualitative field test by a female Magic Marine test rider in changing test conditions (wind speeds varying up to 15 knots). Following the field test, the subject filled in a questionnaire consisting of three parts: (1) comfort while hiking (perception of stiffness, support, boat feel), (2) ergonomics (fit to the body, top layer feel, placement inside the wet-suit) and (3) overall comfort (overall opinion).

4. Experimental results

4.1. Laboratory test

The results of the laboratory test are described by the following figures. The pressure distribution of the various set-ups is depicted in figure 7. For reference purposes, a grey area indicates the entire pad surface area. Pressure in the situation without a hiking pad is >10 kPa. The maximum pressure measured both with the existing hiking pads and the new design is similar (4.5 – 5.5 kPa). However, the area over which it is present is much smaller in the new design.
4.2. User tests

After having tested the new hiking pads, the Magic Marine tester stated: ‘The new pads are a lot better and in their genre, they are the best I’ve tested so far’ and ‘Under 15 knots the new pads rule’. Further results from the questionnaire, as mentioned by the subject are: improved edges, support and body contact and better placement in the wet-suit. These improvements were in line with the already proposed final design, but could not be evaluated since the test user was using an altered MagicMarine battenpad without these design elements.

5. Conclusions

The experimental test set-up provided reproducible test results and provided valuable insight into the development potential and results of the redesign process. The prototypes of the new designed hiking pads showed an improved force distribution although the maximal pressure with existing and new design pads is identical.

The results from the user test (n=1) can only be seen as indicative but not representative for the user group.

6. Discussion and recommendations

Although first field test shows promising results, a full user test on perceived comfort will have to show the possible benefits of the new hiking pads over the existing ones.

The tests described in this paper are performed with a prototype based upon the existing hiking pads. Using full-featured prototypes will provide more insight into the effect of design improvement options such as edge geometry and seam reduction.

This research project focused on the pressure on the thighs, the sailors’ calves however are stressed highly as well. It is therefore recommended to investigate the opportunities of reducing discomfort by stress reduction in the calves. Next to this, the sailors comfort can be improved by supporting the ankle, knee and hip/spinal area.

User research, performed during the early phases of the design project already pointed out that positioning the pads in the wet-suit is important. Therefore, it is recommended to consider a positioning system (i.e. grid printed inside the wet-suit) to enable easy (and repeatable) positioning of the pads inside the wet-suit.
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