Assessment of Action in the Upper Part of the Body on Upwind Dinghy Sailing Performance using a Differential GPS

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In competitive sailing where a race course is marked out by anchored floats on the sea surface, close-hauled, sailing, a technique for sailing upwind, accounts for about 60% of total race time. While sailing close-hauled, waves from the upwind direction cause the boat to slow down, and in order to minimize deceleration, the sailor leans the upper body backward. The present study investigated the effects on boat speed of the posterior leaning of the upper body while sailing close-hauled. Subjects were six male competitive sailors, and the study was conducted using an international Laser class single-person dinghy. The study was conducted in a hike out condition with wind speeds of 5-7 m/s with or without the upper body leaning. Boat speed was measured using D-GPS (20 Hz, Hemisphere), and a digital camera was used to capture the movements of the sailor in the dinghy. In data analysis, an average speed per two-minute period was used to calculate deceleration based on the maximum and minimum velocities while going over waves. The results showed no significant differences in average velocity with or without the upper body leaning while riding in the left or right side of the boat. However, for an expert sailor, the upper body leaning significantly increased boat velocity. No significant differences were seen in deceleration with respect to the upper body leaning. The results suggest that for top-level competitive sailors, the upper body leaning is important and is a factor that affects boat speed.

Key Words: *Upwind Dinghy Sailing, D-GPS, Action in the Upper Part of the Body*

INTRODUCTION

In competitive sailing (yachting), close-hauled sailing is a technique used to sail upwind, and it is possible to sail upwind by repeating close-hauled sailing and tacking (change of direction). In close-hauled sailing, the boat is subjected to waves while sailing upwind, and waves slow the boat down. Posterior leaning of the upper body (hereinafter referred to as body action) is a technique that minimizes boat deceleration by the sailor leaning the upper body backward while the boat hits a wave and is going over a wave. Investigating body action is important for improving the speed of close-hauled sailing. However, to the best of our knowledge, no study has scientifically analyzed the effects of body action in competitive sailing. The present study was conducted to ascertain the effects on boat speed of body action during close-hauled sailing.

Table1 Characteristics of study subjects

subject	Height (cm)	Weight (kg)	Age (years)
A	173	80	29
B	181	83	44
C	179	80	21
D	176	77	24
E	179	68	20
F	176	70	21
Ave.	177.3	76.3	26.5
S.D.	±2.9	±6.0	±9.2

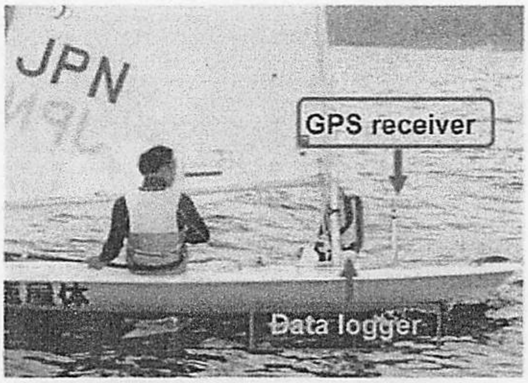

Figure1 A high-performance differential global position system (GPS) unit (Crescent A100, 20 Hz, Hemisphere) was placed in the bow of the boat to measure boat speed

METHODS

Subjects were six male competitive sailors (average height: 177.3±2.9 cm, average body weight: 76.3±6.0 kg, and average age: 26.5±9.2 years). The study was conducted using a single-person Laser class dinghy. The study was conducted in a hike-out condition with wind speeds of 5-7 m/s. Each sailor was instructed to sail close-hauled for 4 minutes. For the first 2 minutes, the sailor was instructed to sail with body action, and for the last 2 minutes, the sailor was instructed to sail without body action. Each sailor made two runs by riding the left and right sides of the boat. While sailing, the sailor was instructed to sail close-hauled as much as possible without using the rudder or main sheet. With body action, the sailor was instructed to lean the upper body backward once per wave, and without body action, the sailor was instructed to maintain normal sailing posture. A single set consisted of a 4-minute run on the left and right sides. Each sailor performed one set, except for Subject A, an expert competitive sailor, who sailed six sets. A high-performance differential global position system (GPS) unit (Crescent A100, 20 Hz, Hemisphere) was placed in the bow of the boat to measure boat speed. A camcorder (SONY) on a motorboat was used to capture the boat and sailor by following the boat on the side from the upwind direction. Wind direction and speed were measured before and after each run. Average speed and deceleration were calculated over each 2-minute period. The rate of deceleration was calculated by dividing the difference between maximum speed

$$\text{The rate of deceleration (\%)} = \left(1 - \frac{\text{min speed}}{\text{max speed}}\right) \times 100$$

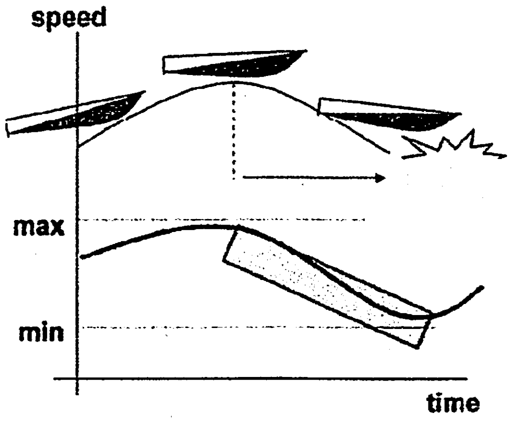

Figure2 The rate of deceleration was calculated by dividing the difference between maximum speed and minimum by the minimum speed while going over a wave

and minimum by the minimum speed while going over a wave. Averages were calculated for each condition. A paired t-test was used to compare averages within each subject, and one-way ANOVA was used to compare averages among the subjects. Significant F values were further subjected to a Bonferroni multiple comparison. Also, in all analyses, the level of significance was set at $p<0.05$, and SPSS 14.0J for Windows was used.

RESULTS and DISCUSSION

Figure 3 shows the average boat speed for all subjects. When riding the left side, the average velocity with body action was 2.38±0.15 m/s and without body action 2.29±0.14 m/s. When riding the right side, the average velocity with body action was 2.42±0.19 m/s and without body action 2.35±0.19 m/s. No significant differences existed in boat speed with or without body action when riding the left or right side.

However, for Subject A, when riding the left side, the average velocity with body action was 2.50±0.07 m/s and without the body action 2.39±0.1 m/s. When riding the right side, the average velocity with body action was 2.43±0.12 m/s and without the body action 2.34±0.11 m/s. Whether riding the left or right side, the average velocity was significantly faster with body action ($p<0.001$ and $p<0.01$, respectively).

The results suggest the efficacy of body action. However, the present study did not closely examine body action. In the future, the technical factors for body action must be closely examined. Also, no significant difference was found in overall average velocity, thus suggesting that body action is a technique with a high level of difficulty. The subjects other than Subject A had not mastered body action, and they might not have properly sailed close-hauled with body action.

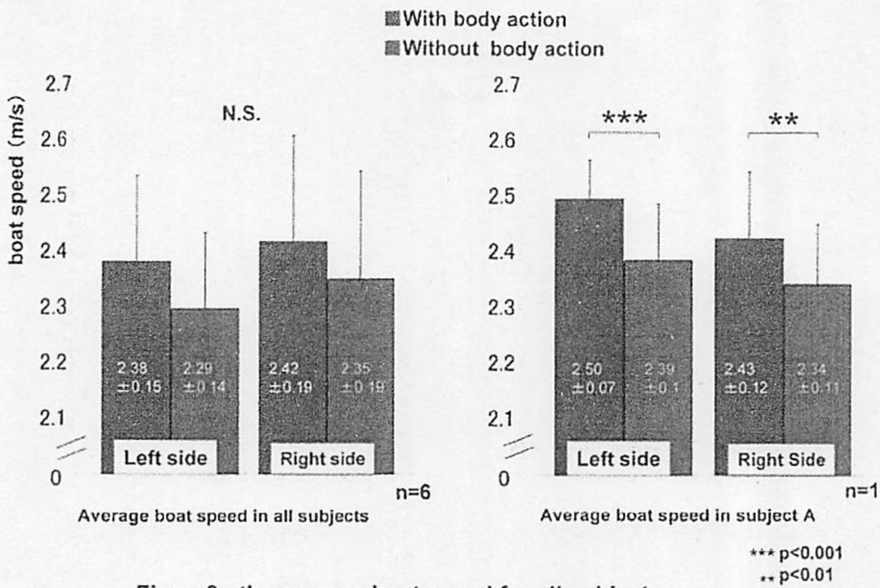

Figure3 the average boat speed for all subjects

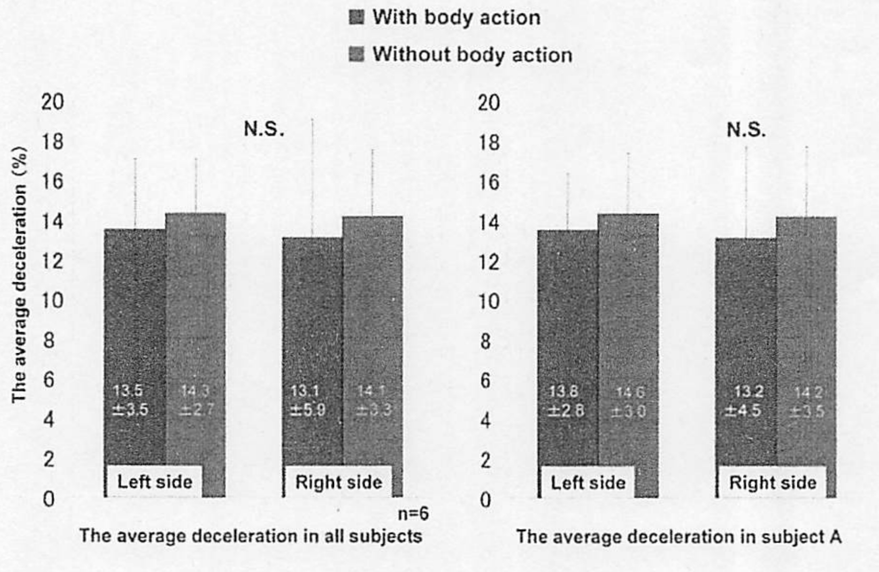

Figure4 The average deceleration for the six subjects and Subject A

Figure 4 shows the average deceleration for the six subjects and Subject A. For the six subjects, when riding the left side, the average deceleration with body action was 13.5±3.5% and without the body action 14.3±2.7%. When riding the right side, the average deceleration with body action was 13.1±5.9% and without body action 14.1±3.3%. No significant differences were found in boat speed with or without body action when riding the left or right side.

For Subject A, when riding the left side, the average deceleration with body action was 13.8±2.8% and without body action 14.6±3.0%. When riding the right side, the average deceleration with body action was 13.2±4.5% and without body action 14.2±3.5%. No significant differences existed in boat speed with or without body action when riding the left or right side.

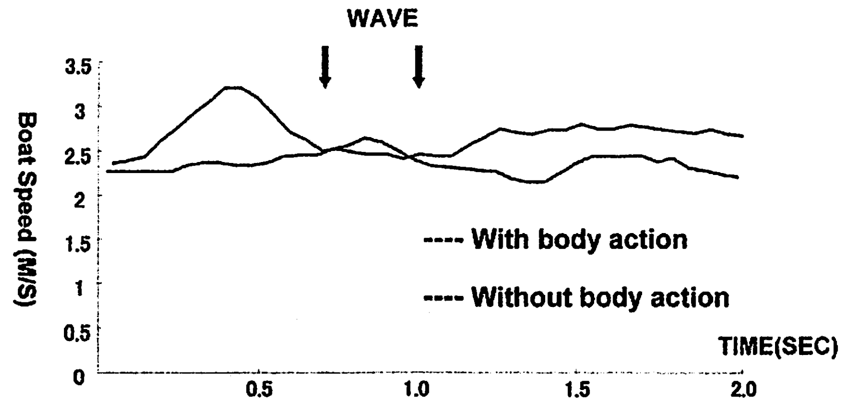

Figure5 Typical example of velocity changes over a 2-second period from when the boat is hit by a wave

In sailing, avoiding waves appears difficult. The types of resistance working on the boat include: (1) viscous friction, (2) viscous pressure, and (3) wave resistance. Viscous friction is unavoidable for boats, and viscous pressure can be minimized by making boats narrow. Wave resistance can be minimized by altering boat shape. Therefore, in the science of naval architecture, many studies have been conducted on the relationship between boat shape and waves. In this manner, the effects of waves can be minimized only by improving boat design.

In the present study, each wave decelerated the boat by about 15%. This information is interesting when considering the effects of waves on the deceleration of Laser class dinghies. The results suggest that the boat absolutely decelerates when hit by waves, and the impacts of waves cannot be sufficiently avoided by body action alone. Therefore, it appears important to control the boat to minimize the impacts of waves rather than to respond after being hit by waves.

Figure 5 shows a typical example of velocity changes over a 2-second period from when the boat is hit by a wave. The arrows in the figure indicate the time point when the boat collided with a wave. Based on the velocity changes, with or without the body action, velocity increased when the boat headed towards the wave peak. This phenomenon was seen when the boat collided with one well-defined wave. Our original assumption was that as the boat heads towards the peak, the boat decelerates as it climbs a slope. However, the data indicate the opposite. The reason for this phenomenon may be that as the boat comes into contact with a wave, lift is generated at the bottom of the boat.

CONCLUSIONS

The present study suggests the importance of body movements for top-level competitive sailors, and body action may be a factor determining boat speed. The present study is significant because the results suggest the possibility of body action being a factor for competitive sailing performance. Deceleration was measured to ascertain the effects of body action on single waves, but body action did not have marked impact on boat speed while going over individual waves. Also, a Laser class dinghy decelerated by about 15% when hit by a wave. Since avoiding waves is difficult, controlling the boat to minimize the impacts of waves seems important, rather than trying to deal with waves after being hit. In the future, the optimal extent and timing of body action must be closely investigated.

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