原著論文

The effects of sprint interval training on sail pumping performance in a male windsurfing Olympian
ウィンドサーフィン競技（RSX 級）男子オリンピック選手のパンピングパフォーマンスに対するスプリントインターバルトレーニングの効果

Masahiro Hagiwara[1, 2)], Toshiyuki Ohya[1, 3)], Ryo Yamanaka[1, 4)], Hayato Onuma[1)], Yasuhiro Suzuki[1)]

萩原正大 [1, 2)]，大家利之 [1, 3)]，山中　亮 [1, 4)]，大沼勇人 [1)]，鈴木康弘 [1)]

Abstract: The aim of this study was to determine the effects of on shore Sprint Interval Training (SIT) using a rowing ergometer on anaerobic and aerobic capacity, and sail pumping performance on water in a male windsurfing Olympian (age: 32 years, competition years: 23, results at Rio Olympic Games in 2016: 15th). Training was in two phases, the first comprising nine sessions over 11 days (three training days alternating with one rest day), and one training session (repeated sets of five maximal effort rowing with 4 min recovery between each set). The second training phase comprised six sessions over 11 days (one training day alternating with one rest day), and two sessions each comprising repeated sets of eight (each set: 20 s maximal efforts rowing and 10 s rest) with a 15 min rest between sessions. Performance tests were implemented three times prior to training, the interval between immediately after completion of all training and before the Rio de Janeiro Olympic Games in 2016, and on return to Japan after this event. The main findings after the training period were that the mean output power in the 1 min all-out rowing test increased ($P<0.01$), and the peak output power tended to increase. In the incremental stage test, the polygonal curve of heart rate (HR) and blood lactate concentrations (BLa) during submaximal exercise shifted to the right, the intensity of onset of blood lactate accumulation (OBLA) tended to increase, and maximal exercise intensity tended to increase. However, maximal aerobic capacity (maximal oxygen consumption and maximal heart rate) did not change. The 2000 m rowing time and mean output power tended to improve. HR decreased during the sail pumping test ($P<0.01$). In summary, SIT using a rowing ergometer in a windsurfing Olympian improved anaerobic capacity, submaximal aerobic capacity, and maximal aerobic performance. These improvements were reflected in indirect improvement in sail pumping

[1]Japan Institute of Sports Sciences, [2]Japanese Olympic Committee, [3]Department of Health Science, School of Health and Sport Sciences, Chukyo University, [4]Department of Medical Sports, Faculty of Health Care and Medical Sports, Teikyo Heisei University

[1] 国立スポーツ科学センター、[2] 日本オリンピック委員会、[3] 中京大学、[4] 帝京平成大学

Dr.Kishi memorial hall, 1-1-1 Jinnan, Shibuya-ku, Tokyo 150-8050, Japan

E-mail: mhagim@gmail.com

performance (reduced cardiorespiratory load) in light wind conditions on water.

Key words: sailing, pumping, anaerobic, aerobic, global positioning system
キーワード：セーリング、パンピング、無酸素性、有酸素性、GPS

I. Introduction

Olympic class windsurfing (RS:X) requires development of sufficiently strong anaerobic and aerobic metabolic pathways [4, 5] and upper and lower body strength [5] to enable increasing or maintaining board speed by sail pumping (rhythmically pulling the sail so that it acts as a wing) [4]. Windsurfers' aerobic capacity is reportedly characterized by maximal oxygen consumption ($\dot{V}O_{2max}$) values of up to 65 mL/kg/min [4, 5, 7, 18], which appears to be higher than other classes of sailor [1]. However, it is unclear whether increasing windsurfers' anaerobic and/or aerobic capacity results in achieving higher board speed by sail pumping.

Castagna et al. [5] have studied the ability of practicing on a rowing ergometer, which closely mimics sail pumping, to enhance windsurfers' anaerobic and aerobic capacity. The UK Olympic sailing team, which is known as a leading team in this sport, has reportedly used a rowing ergometer [8]. Although no details of this research have been published, it suggests that rowing training may have beneficial effects on anaerobic and aerobic capacity and windsurfing performance (sail pumping),

In a previous study of rowing training, it was found that high intensity interval training (6–8 repeats of 2.5 min rowing at maximal exercise intensity separated by recovery until return to 70% of maximal heart rate) increased aerobic capacity with $\dot{V}O_{2max}$ and power output at lactate threshold; moreover, it improved 2000 m rowing time trial [14]. However, there is no reported evidence that rowing training improves both anaerobic and aerobic capacity.

It was recently reported that a novel type of high-intensity interval training known as Sprint Interval Training (SIT; 4–6 repeats of 30 s maximal efforts cycling separated by 4 min recovery) enhances both anaerobic and aerobic capacity [6, 9, 12, 13]. A similar approach, high-intensity intermittent training (7–8 repeats of 20 s cycling at 170%$\dot{V}O_{2max}$ separated by 10 s recovery) simultaneously improves both anaerobic and aerobic capacity [17]. Thus, protocols involving repeated sprint or supramaximal cycling exercise increase anaerobic and aerobic capacity, indicating that such rowing training could be effective.

However, cycling and rowing are clearly different types of exercise. Maximal efforts cycling involves continuous output of power by both legs, whereas maximal efforts rowing has two alternating output of power phases, namely a dynamic (drive: catch to finish) and static (recovery: finish to catch) phase. Thus, we postulated that a smaller physical load is imposed in maximal effort rowing than cycling, even when both are at maximal effort for the same duration. Accordingly, we anticipated that the exercise duration or intensity in the present study should be higher than previous study [6, 9, 12, 13, 17].

On the basis of the above findings, we hypothesized

that modified SIT using rowing exercise would improve windsurfers' anaerobic and aerobic capacity and thus windsurfing performance in terms of board speed with sail pumping. The aim of this study was to determine whether one month of rowing SIT before the Rio de Janeiro Olympic Games (Rio-2016) improved the anaerobic and aerobic capacity and windsurfing performance (sail pumping) in a male Olympian windsurfer.

II. Methods

1. Participant

A male windsurfing Olympian who was to compete at Rio-2016 (age: 32 years, competition years: 23, result at Rio-2016: 15th) was the only participant in this study. This athlete had competed in two prior Olympic Games (Beijing-2008, London-2012) and had trained for those events by using a rowing ergometer. He therefore volunteered to again perform SIT in rowing before Rio-2016. The purpose, procedures, and possible risks of this study were explained to him and he gave written, informed consent. Prior to participating in this study, he had a medical check-up and the study was performed in accordance with the ethical standards of the Declaration of Helsinki.

2. Overview of the study protocol

Figure 1 shows the schedule for training, performance testing, and competing at Rio-2016. Training was in two phases, the first in Japan and the second after traveling to Brazil to compete at Rio-2016. Performance testing took place three times; namely, prior to training (PRE), 2 days after completion of training and before Rio-2016 (POST1), and after returning to Japan after Rio-2016 (POST2). Thus, POST2 was conducted 3 weeks after completion of training. These three performance tests were conducted within 2 days of each specified testing point (PRE, POST1, POST2), and the first training phase started the day after PRE. Additional training engaged in by the participant according to his own schedule and separate
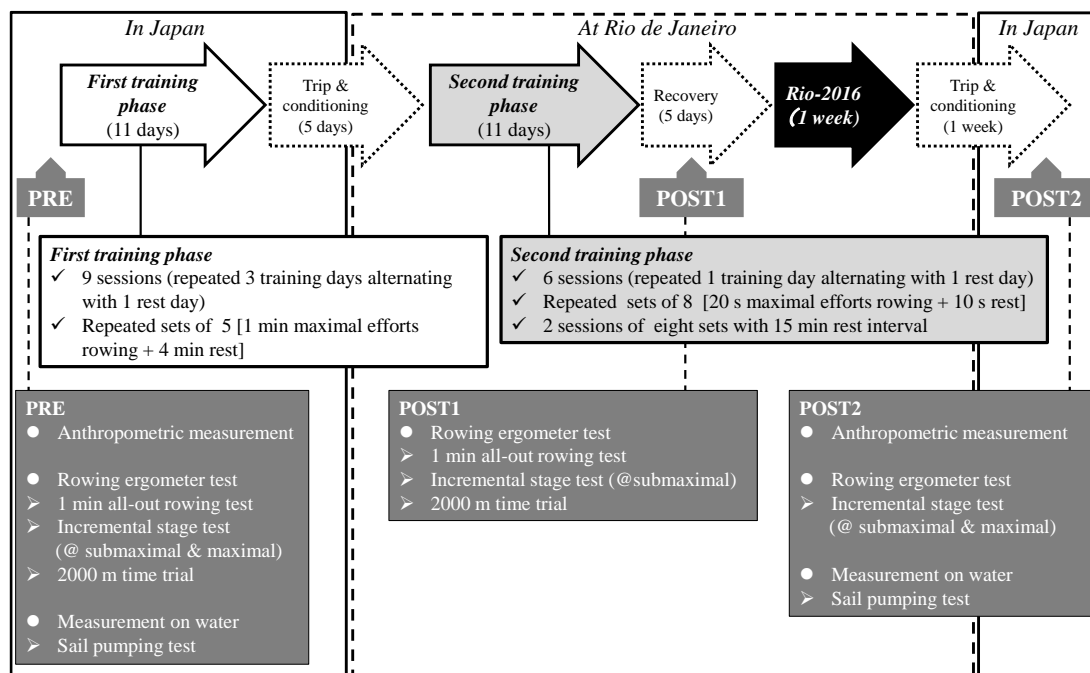

Fig. 1. Overview of the protocol for this study

Table 1. Athlete's own schedule separate to study protocol

Phase	Running using treadmill	Resistance training	Rowing using ergometer	On water training
First training phase (11 days)	Running speed: 11 to 17 km/h. (Increased 1 km/h every 3 min) *Self-intensity: RPE 11 to 13 frequency: 5 days/week.	①Self-weight: Core-related. ②Weight load: Pull-related and Push-related in upper body. @15 RM-intensity @5 to 10 reps, 3 to 4 sets (Just stimulate muscle without muscular hypertrophy)	Aerobic training. @10 to 15 min/day. @80% to 90 % OBLA@PRE-intensity. Repeated 3 training days and 1 rest day.	Voluntary sailing. @2 to 3 h/day. Repeated 3 training days and 1 rest day.
Second training phase (11 days)	Running speed: 11 to 17 km/h. (Increased 1km/h every 3 min) *Self-intensity: RPE 11 to 13 frequency: 5 days/week.	None.	None.	Sailing race@ 2 to 3 h/day, Training almost every day. (Rests for 2 days)

to the training in this study is shown in Table 1.

3. Training regimes

   1) First training phase

The SIT in the first training phase comprised nine sessions over 11 days (three training days alternating with one rest day). The sessions comprised repeated sets of five maximal efforts of SIT rowing with 4 min recovery between each set, the duration of exercise being 60 s. The athlete was encouraged verbally during every training.

   2) Second training phase

The SIT in the second training phase comprised six sessions over 11 days (one training day alternating with one rest day). In these sessions, exercise intensity was achieved by maximal effort. Each session of SIT comprised repeated sets of eight (one set: 20 s maximal effort rowing and 10 s active rest), a 15 min rest, and then another session.

4. Anthropometric measurements

The athlete's height was measured with an automated height scale (AD-6228A; A&D, Tokyo, Japan) and his body weight and percentage of body fat determined by a body composition analyzer (Inbody-770; InBody, Tokyo, Japan) at PRE and POST2.

5. Performance test using rowing ergometer on shore

All performance tests to evaluate anaerobic and aerobic capacity were conducted on shore using a rowing ergometer (Model D, Concept, Vermont, US).

These tests commonly started with a 5 min warm up at 150 W with two rowing sprints (around 10 s) in the second and fourth min and an additional 5 min rest.

   1) 1 minute all-out rowing test

A 1 min all-out rowing test was performed to determine peak output power (W_{peak}) and mean power (W_{mean}) of the whole exercise, and peak blood lactate concentrations (BLa_{peak}) after exercise. The athlete was instructed to begin rowing to output power as strongly as possible, and maintain to output power as high as possible as well.

One, three and five min after the end of the 1 min all-out rowing, ear lobe blood samples (0.3 μL) were collected to measure blood lactate concentrations (BLa) using an enzymatic-amperometric detection method (Lactate Pro 2 LT-1730; Arkray, Kyoto, Japan).

   2) Incremental stage test

The incremental stage test using rowing ergometer was performed two patterns of protocol successively. The first protocol was to determine submaximal aerobic capacity, and the second protocol was to determine maximal aerobic capacity. The athlete started at 190 W, the power output was increased by 30 W every 3 min exercise. The measurement of submaximal aerobic capacity in first protocol was conducted until a BLa of 4 mM/L was reached, with 1 min rest between each stage. After a BLa was reached, the measurement of maximal aerobic capacity in second protocol was

performed without any rest until volitional exhaustion.

Both submaximal and maximal aerobic capacity were measured at PRE and POST2, only the measurement of submaximal aerobic capacity was conducted at POST1.

The heart rate (HR) was recorded each 5 s with a heart rate monitor (RS800cx; Polar Electro, Kempele, Finland) and the HR of the last 30 s of each submaximal exercise stage of the test was averaged. The peak HR (HR_{peak}) was defined as the highest HR during this test.

Oxygen uptake ($\dot{V}O_2$) was determined by measuring breath-by-breath respiratory gas exchange using an automated analysis system (AE-310s; Minato Medical Science, Osaka, Japan). Before this test, the gas analysis system was calibrated using a gas mixture with known O_2 and CO_2 concentrations and the volume transducer calibrated using a 2-L syringe. Respiratory gas exchange values were averaged every 30 s during this test. The peaks of $\dot{V}O_2$ ($\dot{V}O_{2peak}$) and $\dot{V}E$ ($\dot{V}E_{peak}$) were defined as the highest $\dot{V}O_2$ and $\dot{V}E$.

During the 1 min rest of the test and 1, 3, and 5 min after the exercise, BLa was measured by the above same procedure as in 1 min all-out rowing test. The intensity of onset of blood lactate accumulation (OBLA) [16] was calculated from the BLa of the incremental stage test. BLa_{peak} was defined as the highest BLa after this test.

3) 2000 m time trial

A 2000 m time trial was performed to determine 2000-m time (s), and mean power (W_{mean}).

6. Performance test of sailing on water

A sail pumping test was conducted using the athlete's gear. The athlete performed 10 cycles of pumping upwind and no-pumping (sailing using harness) at 30 s intervals, the pumping first and next no-pumping with starboard side only. The athlete was instructed to sail at "as high a board speed and with as small a board angle as possible", to simulate race conditions. This enabled evaluation of Velocity Made Good (VMG), an established indicator of sailing performance (Fig. 2). Incidentally, there were similar light wind conditions (ranging from 3 to 4 m/s) on the test days for PRE and POST2.

The HR was recorded by the same procedure as in the incremental stage test. HR during pumping and no-pumping was averaged for each 30 s.

Wind data (direction and speed) were measured using a wind measurement instrument (High Accuracy Wind Measurement System, North Sail Japan, Kanagawa, Japan) on an inflatable boat (VSR5.8c, VSR LAB, Portorose, Slovenia). This system consists of a wind direction and speed sensor that utilizes ultrasound, a sensor for boat position and heading that utilizes a GPS fixed to a mast, a control box for collecting and calculating all data from the sensors, and a tablet computer for logging and displaying wind data. The wind sensor was calibrated to offset direction (zero set) with the boat heading in a straight line on a windless day. The boat heading sensor was calibrated to magnetic direction using a compass that drew on GPS data. The wind data were measured from an inflatable boat that kept as close as possible to the athlete performing the pumping test while ensuring its position had no negative effect on wind data accuracy (Fig. 3). The wind data were recorded at 1 Hz and averaged.

The athlete's board speed and angle were measured using a GPS (SPI-ProX, GPSports, Canberra, Australia) that was fixed inside the mast sleeve of the sail. The GPS data were recorded at 15 Hz and these data and wind data synchronized at 1 Hz. VMG was calculated from GPS and wind data obtained. (Fig. 2).
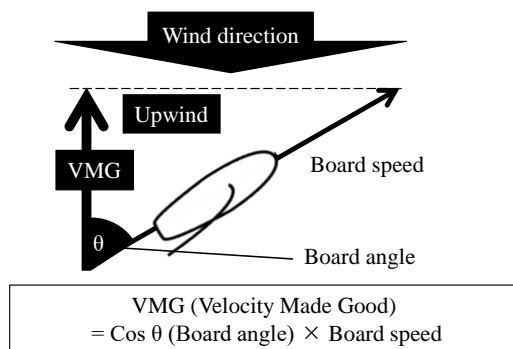
7. Statistical analysis

$$VMG \text{ (Velocity Made Good)} = \text{Cos } \theta \text{ (Board angle)} \times \text{Board speed}$$

Fig. 2. Calculation of Velocity Made Good (VMG)

Fig. 3. Positioning of inflatable boat for wind data measurement

The W_{mean} of the 1 min all-out rowing test and HR and VMG values during the sail pumping test are expressed as mean ± standard deviation (SD). Statistical analyses were performed using SPSS (ver. 22.0, SPSS, Illinois, USA). Student's paired t-test was used to determine the significance of differences between PRE and POST1 in the W_{mean} of the 1 min all-out rowing in performance test. HR and VMG values (averages of every 10 data during the sail pumping test) were assessed using two-way (training period [PRE vs. POST2] × sailing style [pumping vs. no-pumping]) repeated measures of analysis of variance (ANOVA) to determine interaction or main effect. When ANOVA revealed significant main effect or interaction, the Bonferroni test was used for *post hoc* analysis. Differences were considered significant if $P < 0.05$.

III. Results

The anthropometric variables did not change greatly between PRE and POST2 (Table 2).

In the 1 min all-out rowing test, the W_{mean} was significantly higher at POST1 than at PRE ($P < 0.01$; Fig. 4) and the W_{peak} and BLa_{peak} tended to be higher at POST1 than at PRE; however, the stroke times did not change (Table2).

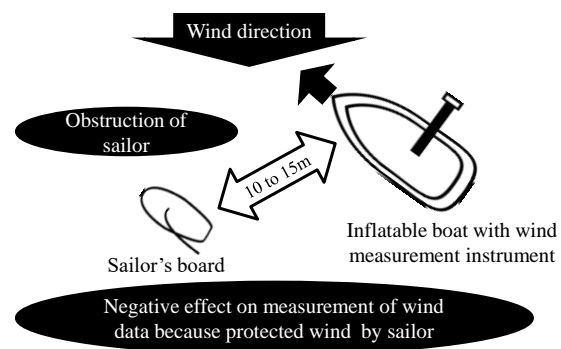In the incremental stage test, OBLA intensity, BLa_{peak} and stage observed $\dot{V}O_{2peak}$ tended to be higher

at POST2 (POST1 for OBLA intensity as well) than at PRE, however the HR_{peak} and $\dot{V}O_{2peak}$ did not change significantly (Table2, Fig. 5). The HR at 190 and 220 W tended to be lower at POST1 and POST2 than at PRE (Fig. 5). The BLa of 220 and 250W tended to be lower at POST1 and POST2 than at PRE (Fig. 5). Thus, the polygonal curve of the HR and BLa during submaximal exercise shifted to the right at POST1 and POST2 compared with at PRE (Fig. 5).

In the 2000 m time trial, the time and W_{mean} tended to improve at POST1 compared with at PRE (Table 2).

The finding for the sail pumping test on water was no interaction (training period [PRE vs POST2] × sailing style [pumping vs. no-pumping]); thus, the only significant differences were in the main effects (training period, sailing style). The average HR on all pumping and no-pumping was significantly lower at POST2 than at PRE ($P < 0.01$; Fig. 6). The average VMG for all pumping and no-pumping did not differ between at PRE and POST2 (Fig. 6), neither did the average board speed and angle change between POST2 and PRE. The HR and VMG were significantly higher during pumping than no-pumping at both PRE and POST2 ($P<0.01$; Fig. 6).

IV. Discussion

In this study, we investigated training directed at

Table 2. Main findings before and after training in this study

Test	Measurement items	PRE	POST1 (Before Rio-2016)	POST2 (After Rio-2016)	Variation: Δ (Gain rate to PRE: %)
	Height (cm)	182.1		182.1	Δ0.0 (0%)
Body composition	Weight (kg)	70.6		70.7	Δ0.1 (0.1%)
	Body fat percentage (%)	6.3		7.2	Δ 0.9 (0.9%)
	W_{peak} (W)	620	646		Δ26 (4.2%)
1 min all-out rowing test	Stroke times (time)	46	46		Δ0 (0%)
	BLa_{peak} (mM/L)	12.5	15.1		Δ2.6 (20.8%)
	OBLA-intensity (W)	222	256	255	POST1 Δ34.4 (15.5%) POST2 Δ33.9 (15.3%)
	HR_{peak} (bpm)	182		182	Δ0.0 (0%)
Incremental stage test	Absolute-VO_{2peak} (L/min)	4.65		4.61	Δ-0.04 (-0.9%)
	Relative-VO_{2peak} (mL/kg/min)	65.9		65.2	Δ-0.7 (-1.1%)
	BLa_{peak} (mM/L)	10.8		13.9	Δ3.1 (28.7%)
	The stage (exercise intensity) observed VO_{2peak}	5 (310W)		6 (340W)	Δ1
2000 m time trial	Time (s)	412.8	407.0		Δ-5.8 (-1.4%)
	W_{mean} (W)	318	332		Δ14 (4.4%)

Mean±SD, **: P<0.01 (PRE vs. POST1)
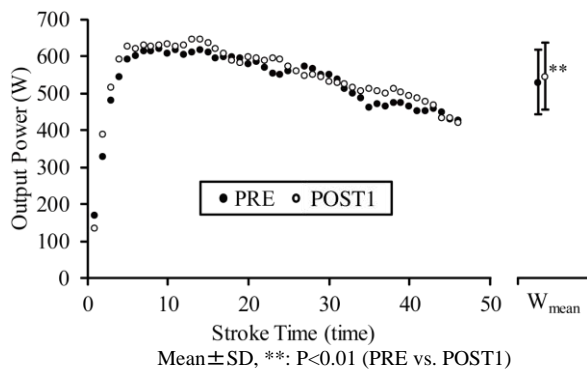
Fig. 4. Output power in 1 min all-out rowing test

Fig. 5. HR and BLa during incremental stage test at submaximal effort

improving anaerobic and aerobic capacity (as well as sail pumping performance indirectly) in a male windsurfing Olympian for one month before Rio-2016.

Our main finding was that the SIT used in this study improved anaerobic capacity, submaximal aerobic capacity, and maximal aerobic performance, anddecreased HR during sail pumping on water post-training. Previous studies on the effect of SIT have reported significant increases in both anaerobic
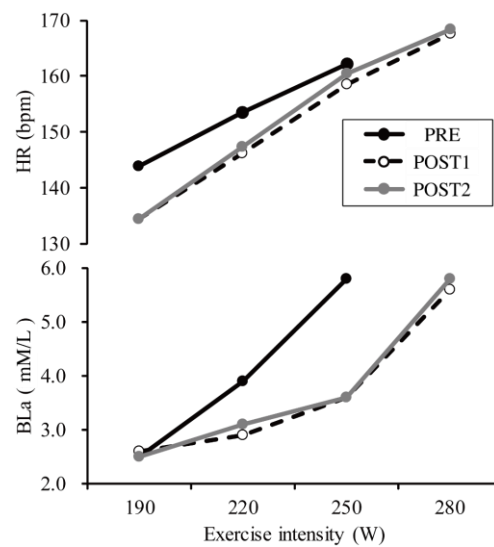
and aerobic capacity [6, 12, 13]. However; there are no previously reported studies on SIT in rowing, The following points are therefore relevant.

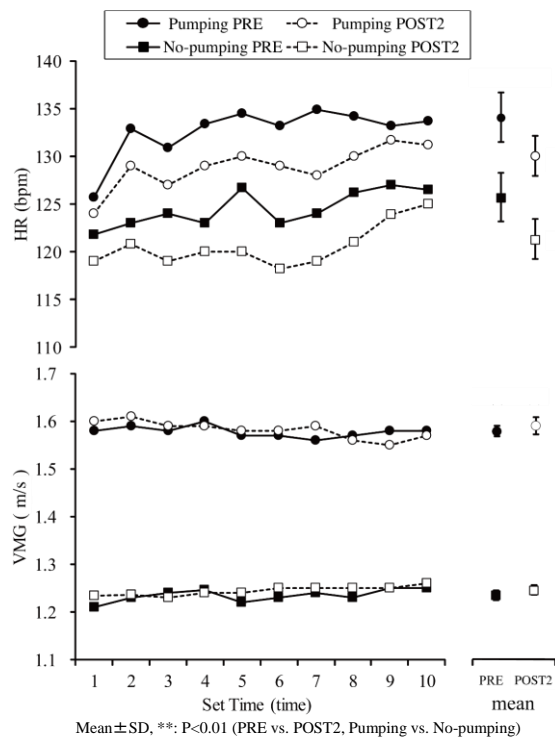The W_{mean} of the 1 min all-out rowing test was significantly greater at POST1 than at PRE (Fig. 4).

Fig. 6. HR and VMG during sail pumping test on water

Additionally, the W_{peak} tended to be higher at POST1 than at PRE (Table 2). These findings indicate that the training undertaken in this study increased power output during anaerobic exercise, which is similar to findings of previous studies on improving anaerobic capacity [6, 12, 13]. Additionally, the BLa_{peak} at the end of each 1 min all-out rowing test and incremental stage test at maximal exercise tended to be greater after the training period (Table 2). Previous studies have reported that BLa_{peak} values tend to increase when measured after SIT using cycling [11, 15]. Moreover, another study has reported that 4 weeks of SIT in trained cyclists increases plasma lactate concentrations and motor unit recruitment in repeated sprint tests [6]. Thus, the sprint stimuli applied were sufficient to elicit neuromuscular changes and increase lactate metabolism. We therefore guessed that the SIT using rowing ergometers in this study might improve

anaerobic capacity as has been found in previous studies.

Previous studies about aerobic capacity have reported that SIT using cycling improves OBLA intensity [13], maximal oxygen uptake [6, 11, 12], and aerobic exercise performance [2, 3, 11, 12]. In this study, the polygonal curve of HR and BLa shifted to the right at POST1 and POST2 compared with at PRE (Fig. 5). Moreover, OBLA intensity in the incremental stage test during submaximal exercise tended to be greater after the training period (Table 2). The improvements in aerobic capacity during submaximal exercise documented in this study are similar to those of a previous study [13].

However in contrast with previous studies [6, 11, 12], in this study $\dot{V}O_{2peak}$ did not change greatly between PRE and POST2 (Table 2). Previous studies have reported that $\dot{V}O_{2max}$ of high competitive windsurfers are probably 65 mL/kg/min [4, 5], the same level as was observed in the athlete in this study (Table 2). It seems that the athlete in this study had developed high level aerobic capacity during maximal exercise prior to PRE. Thus, the SIT protocol in this study may be insufficient to improve maximal aerobic capacity in a high level windsurfer. However, maximal aerobic performance (the stage at $\dot{V}O_{2peak}$) was greater at POST2 than at PRE (Table 2). Thus, in this study SIT may have improved maximal exercise intensity by increasing exercise efficiency even in the absence of change in maximal aerobic capacity ($\dot{V}O_{2peak}$).

Taking our findings together, we consider that the improvement in the 2000 m time trial (time, W_{mean}) was attributable to increased anaerobic capacity, submaximal aerobic capacity, and maximal aerobic performance despite the lack of change in maximal aerobic capacity. Interestingly, the improvement in

aerobic capacity during submaximal exercise persisted until POST2. This may indicate that the effects of the training undertaken in this study persist for 3 or more weeks.

We postulate that the training undertaken in this study was of sufficient intensity and volume to result in improvement in submaximal aerobic capacity and maximal aerobic performance, but not enough to improve maximal aerobic capacity. Another important point is that the duration of SIT effect remains unclear. Further studies are required to clarify these.

Meanwhile, to the best of our knowledge, no published studies have investigated the physiological effects of training sailors on their performance; specifically, the effect of training on sailing performance (VMG) has not been evaluated. Thus, the original aspect of this study is that the effect of training was assessed via both physiological variables and sailing performance (VMG).

The HR during sail pumping and no-pumping on water were significantly lower at POST2 than at PRE; however, the VMG did not change (Fig. 6). These findings suggest that sail pumping at POST2 imposed a lower cardiorespiratory load than at PRE, even when performing at the same VMG. Previous studies have shown that Olympic class windsurfing imposes high cardiorespiratory and BLa demands during sail pumping, these being close to the maximal values recorded when performing maximal exercise to exhaustion on shore [4, 5]. Moreover, Castagna et al. [5] have postulated that lactic acidosis may be the limiting factor for muscle performance because BLa during sail pumping suggests substantial involvement of anaerobic metabolism. Thus, in this study the SIT using rowing decreased cardiorespiratory load during sail pumping while performing the same VMG, indicating there is

extensive dependence on aerobic energy pathways rather than lactate metabolism during windsurfing racing.

We also postulate that the lack of change in this athlete's VMG is attributable to his having already achieved his top level for VMG while sail pumping and therefore having limited trainability in this regard. He had already placed third in a previous world cup under pumping conditions (light wind) and finished second in a race in light wind at Rio-2016. Thus, the training undertaken in this study benefited this top athlete's sail pumping, not by improving VMG but by reducing the cardiorespiratory load. However, whether SIT improves VMG in less accomplished athletes is open to debate.

Another possible explanation for the lack of change in VMG after the training period is the lack of adaptive time and/or training program to apply to sail pumping on water. In addition, the sail pumping on higher than light wind speed conditions in this study (range from 3 to 4 m/s) required a greater output power to increase or maintain board speed. Thus, the training in this study may have been effective in increasing VMG. These above possibilities require further investigation.

The HR and VMG during pumping were significantly higher than during no-pumping at both PRE and POST2 (Fig. 6). A previous study has reported that sail pumping entails greater exercise intensity than no pumping [18], which is consistent with our finding that HR was different with or without pumping (Fig. 6). Nevertheless, the reason for sail pumping is to provide the board with additional propulsion, no previous studies have compared board speed during sailing with or without pumping on water. Therefore, we here present unique evidence about changes in VMG.

As stated above, in the present study the SIT using

rowing ergometers was improved anaerobic and aerobic capacity for windsurfing athlete. These improving contributed not only to enhance performance on rowing ergometers, but also to reduce the cardiorespiratory load during sail pumping. These findings provide new and useful information about training for windsurfing athletes.

There is a limitation of this study. By unavailability of the analyzer at Rio-2016 venue, we could not evaluate $\dot{V}O_{2peak}$ at POST1. If we could have examined whether $\dot{V}O_{2peak}$ increased at POST1, more information would be provided. This possibility requires further investigation.

V. Practical applications

This is one of only a few studies providing valuable data concerning a Japanese Olympian. Our data will be helpful for competitive windsurfing athletes. The SIT using rowing ergometers in this study proved to be an effective means of improving anaerobic capacity, submaximal aerobic capacity, maximal aerobic capacity and, indirectly, sailing performance.

SIT using rowing ergometers on shore can be done indoors anytime, which is useful when inclement weather prevents sailing. Training using a rowing ergometer is reportedly used for every Olympic class sailing team from UK, which is known as a leading nation [8]. Additionally, evaluation of sailing performance using VMG is valuable when analyzing essential factors contributing to sailing performance. Thus, if the relationships between VMG and other various factors (e. g., physiological, biomechanical, meteorological) were ascertained, they might contribute to enhancing sailing performance in practice. SIT using rowing ergometers and assessment of VMG might benefit not only windsurfing athletes, but also other sailors.

VI. Conclusions

In the Japanese windsurfing Olympian, SIT using a rowing ergometer improved anaerobic capacity, submaximal aerobic capacity, and maximal aerobic performance. Indirectly, these improvements were reflected in the improvement of sailing performance (e. g., cardiorespiratory load) on water.

References

1) Bojsen-Møller J., Larsson B., Aagaard P., Physical requirements in Olympic sailing. Eur. J. Sports Sci., 15(3): 220-227, 2015.

2) Burgomaster K. A., Cermak N. M., Phillips S. M., Benton C. R., Bonen A., Gibala M. J., Divergent response of metabolite transport proteins in human skeletal muscle after sprint interval training and detraining. Am. J. Physiol. Regul. Integr. Comp. Physiol., 292: 1970-1976, 2007.

3) Burgomaster K. A., Heigenhauser G. J., Gibala M. J., Effect of short-term sprint interval training on human skeletal muscle carbohydrate metabolism during exercise and time-trial performance. J. Appl. Physiol., 100: 2041-2047, 2006.

4) Castagna O., Vaz Pardal C., Brisswalter J., The assessment of energy demand in the new Olympic windsurf board; Neilpryde RS:X. Eur. J. Appl. Physiol., 100: 247-252, 2007.

5) Castagna O., Brisswalter J., Lacour J. R., Vogiatzis I., Physiological demands of different sailing techniques of the new Olympic windsurfing class. Eur. J. Appl. Physiol., 104: 1061-1067, 2008.

6) Creer A. R., Ricard M. D., Conlee R. K., Hoyt G. L., Parcell A. C., Neural, metabolic, and performance adaptations to four weeks of high intensity sprint-interval training in trained cyclists. Int. J. Sports Med., 25: 92-98, 2004.

7) De Vito G., Di Filippo L., Rodio A., Felici F., Madaffari A., Is the Olympic boardsailor an endurance athlete? Int. J. Sports Med., 18(4):281-284, 1997.

8) Fletcher E., Indoor rowing; Sailing Guide. http://www.rya.org.uk/SiteCollectionDocuments/Racing/Web%20Documents/Concept2_sailing_guide.pdf.

9) Gibala M. J., McGee S. L., Metabolic adaptations to

short-term high-intensity interval training; a little pain for a lot of gain?. Exerc. Sports Sci. Rev., 36: 58-63, 2008.

10) Gibala M. J., Little J. P., van Essen M., Wilkin G. P., Burgomaster K. A., Safdar A., Raha S., Tarnopolsky M. A., Short-term sprint interval versus traditional endurance training; similar initial adaptations in human skeletal muscle and exercise performance. J. Physiol., 575: 901–911, 2006.

11) Harmer A. R., McKenna M. J., Sutton J. R., Snow R. J., Ruell P. A., Booth J., Thompson M. W., Mackay N. A., Stathis C. G., Crameri R. M., Carey M. F., Eager D. M., Skeletal muscle metabolic and ionic adaptations during intense exercise following sprint training in humans. J. Appl. Physiol., 89: 1793-1803, 2000.

12) Hazell T. J., Macpherson R. E., Gravelle B. M., Lemon P. W., 10 or 30-s sprint interval training bouts enhance both aerobic and anaerobic performance. Eur. J. Appl. Physiol., 110(1): 153-160, 2010.

13) Ijichi T., Hasegawa Y., Morishima T., Kurihara T., Hamaoka T., Goto K., Effect of sprint training; training once daily versus twice every second day. Eur. J. Sports Sci., 15: 143-150, 2015.

14) Ní Chéilleachair N. J., Harrison A. J., Warrington G. D., HIIT enhances endurance performance and aerobic characteristics more than high-volume training in trained rowers. J. Sorts Sci., 35(11): 1052-1058, 2017.

15) Sharp R. L., Costill D. L., Fink W. J., King D. S., Effects of eight weeks of bicycle ergometer sprint training on human muscle buffer capacity. Int. J. Sports Med., 7: 13-17, 1986.

16) Sjödin B., Jacobs I., Onset of blood lactate accumulation and marathon running performance. Int. J. Sports Med., 2(1): 23-26, 1981.

17) Tabata I., Nishimura K., Kouzaki M., Hirai Y., Ogita F., Miyachi M., Yamamoto K., Effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and VO2max. Med. Sci. Sports Exerc., 28(10): 1327-1330, 1996.

18) Vogiatzis I., De Vito G., Rodio A., Madaffari A., Marchetti M., The physiological demands of sail pumping in Olympic level windsurfers. Eur. J. Appl. Physiol., 86: 450-454, 2002.