

ECG Monitoring on Swimming Endurance and Heart Rate of Jack Mackerel *Trachurus japonicus* during Repeated Exercise

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Abstract

The swimming performance of jack mackerel after post-exercise recovery was evaluated through electrocardiograph (ECG) monitoring. Jack mackerels were forced to swim in the flume tank, with the swimming speed levels of 1.09-9.12 fork length per second (FL·s⁻¹) at 15 °C and 22 °C. Firstly, the heart rate was monitored in still water as a control, and continuously to observe the heart rate during exercise for 200 min or until fatigue as the 1st exercise trial. The post-exercise recovery was observed after stopping the flow as the 1st recovery phase. Secondly, after confirming the complete recovery of fish monitored by ECG, the same fish was again forced to swim as the 2nd exercise trial. The heart rate activity was also continuously observed in the 2nd recovery phase. The swimming endurance and heart rate patterns were the same between the 1st and 2nd exercise at respective swimming speed level for 15 °C and 22 °C. It is therefore suggested that previous capture of fish by an active fishing gear involving swimming and exhaustion may not have an impact on its ability to respond to the gear in the subsequent encounter if the fish is able to get complete recovery from the previous encounter.

Introduction

Modern trawls vary in gear scales to allow different types of fishing boats to tow them at a maximum speed: between 3-4 knots when using full power (Wardle 1993). Those speeds correspond to swimming speed of 10.8 and 14.4 fork length per-second (FL·s⁻¹) for fish size of average fork length 18.2 cm in this experiment, where fish was swimming in prolonged and burst swimming speed level. This illustrates that the fish may need to swim very hard to escape and avoid the trawl and other mobile fishing gears during capture processes. The

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simulated experiment in the flume tank showed fish was completely exhausted at prolonged swimming speeds just for several minutes (Nofrizal et al. 2008; 2009).

Physiologically, this indicates the high increase of heart activity at the vicinity of maximum sustained swimming speed and reached maximum value at the prolonged and burst swimming speed (Nofrizal et al. 2008). Hence, tachycardia activities occur when swimming at the maximum sustained, prolonged and burst swimming speed. Thus, fish requires a longer time, up to 9 hours, for recovery after complete fatigue at prolonged swimming speed (Nofrizal et al. 2009). The recovery time and increment of the heart rate illustrate the stress and fatigue level of fish during and after swimming to escape from the capture process. The condition of fish after post-exercise recovery or escaping from the gears is generally unknown. This study is to evaluate the swimming performance of jack mackerel after repeated exercise trials to simulate the post-exercise effect after encountering with fishing gear, through ECG monitoring for heart rate activity.

Materials and Methods

Experimental fish

Jack mackerels of fork length 18.2 ± 0.7 cm (average \pm S.D., $n = 16$) were obtained from a fish farm at Suruga Bay, Japan. Fish were transported by a live fish transportation truck to the Fish Behavior Laboratory of the Tokyo University of Marine Science and Technology where they were kept in a tank measuring 2.0 m long, 0.9 m wide and 1.0 m deep. The fish were fed fish meal pellets every day during both the acclimation and experiment period, and water in the keeping tank was continuously purified and aerated.

Flume tank and ECG observation system

The flume tank (West Japan Fluid Engineering Laboratory, PT-70) used in this study was specially designed to provide most of the test section, (70 cm long, 30 cm wide and 20 cm deep) with a steady water flow (Fig. 1). One side of the wall of the test section was covered by a panel upon which square grids were drawn as visual cues for maintaining position in the flow through the optomotor response (He and Wardle 1988; Wardle 1993; Xu et al. 1993; Nofrizal et al. 2008; 2009). When a test fish was maintaining its position relative to the oncoming flow, the swimming speed of the fish was considered to be equivalent to the flow speed.

The heart rate activity was measured by a pair of electrodes, which was connected to an oscilloscope through bio-Amplifier (Fig. 2). Fish was anesthetized by FA 100 (0.008%) for 15-20 min, before a pair of electrodes was implanted in the pericardial cavity of each jack mackerel under anesthesia. The electrodes were made of enamel-insulated tungsten pins (MT Giken), and were 15 mm long and 0.2 or 0.3 mm in diameter. The outer insulation of the

electrode was removed from both tips for a length of 1 mm, and the electrodes were inserted into the pericardial cavities of the fish from the ventral side.

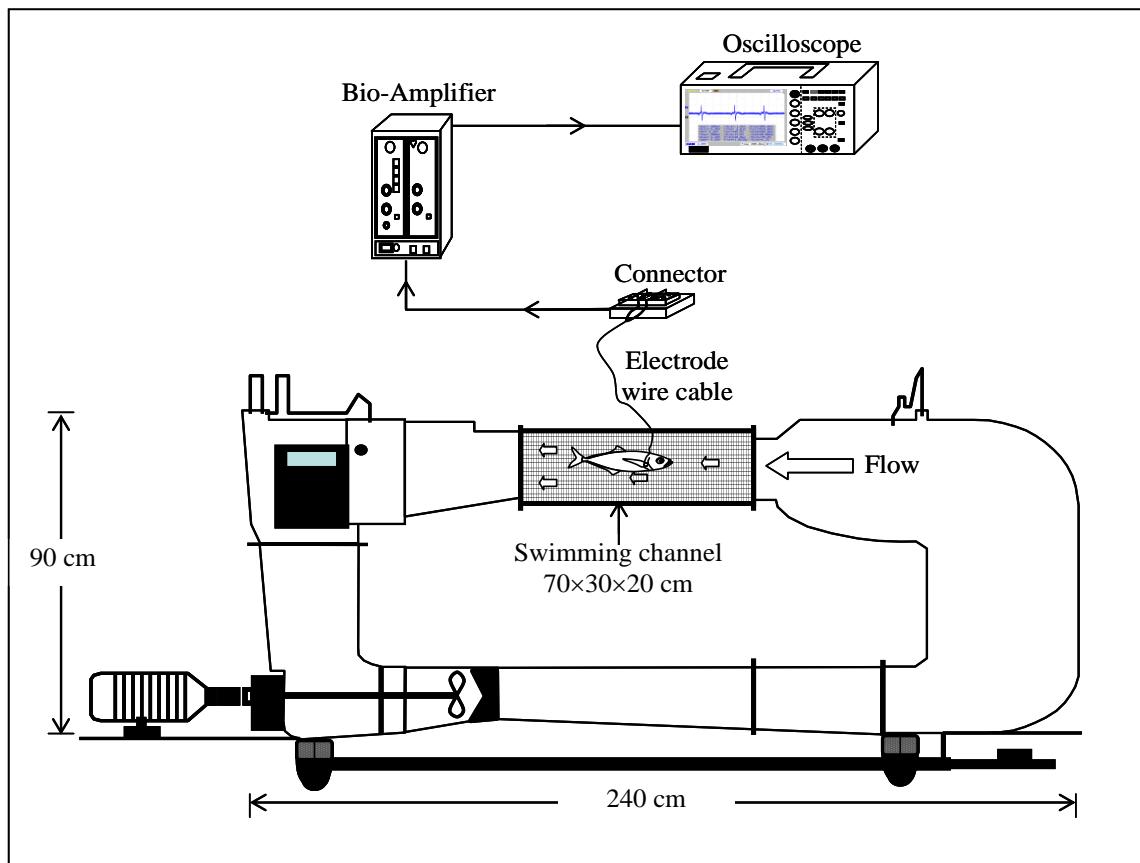


Fig. 1. Experimental apparatus for swimming endurance and ECG monitoring

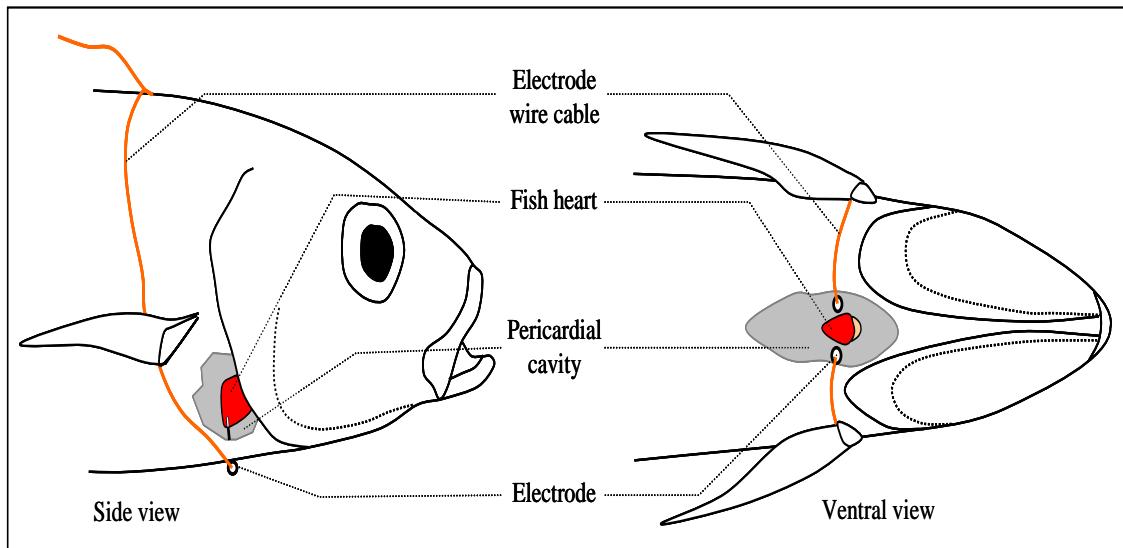


Fig. 2. Position of the pair electrodes used to monitor the heart beat

Electrodes were fixed to the left and right sides of the ventricle of the heart to monitor the heart beat (An and Arimoto 1994; 1997; Ito et al. 2003; Nofrizal et al. 2008; 2009). The electrodes were connected to copper wire cable (Tsurumi Seiki, T-GA XBT cable) and covered with superglue (Aron Alpha, Toagosei). The other end of the wire cable was

connected to a digital oscilloscope (Iwatsu, DS-5102) via a bio-amplifier (Nihon Kohden, Bioelectric Amplifier AB-632J), as shown in Fig. 1.

Experimental protocol

The heart rate (beats·min⁻¹) of each fish was measured in still water for 10 min, as the control, after subsequent recovery from anesthesia for 180 min. The heart rate observation was conducted continuously in swimming exercise at flow speed of 20.4 to 160.4 cm·s⁻¹, which corresponded to the swimming speed of 1.1 to 8.5 FL·s⁻¹. The heart rate activity was observed during the 1st swimming exercise for 200 min or until fatigue of an individual fish. The observation of heart rate was conducted continuously in the 1st post-exercise recovery after the flow velocity was stopped. The same speed level was given at each individual sampling after completing the 1st post-exercise recovery for the 2nd exercise test. The observation of heart rate activity in post-exercise recovery was limited when the heart rate was equal to maximum value of control (Ito et al. 2003; Nofrizal et al. 2009).

Data analysis

Relationship between swimming speed and endurance time was analyzed by semi-log linear regression at each temperature. Comparison of swimming endurance time and heart rate between 1st and 2nd exercise trials was analyzed by x-axis is equal y-axis at respective swimming speed levels. Trend of the heart rate and recovery time according to swimming speed was expressed by XY scatter graph to compare pairs of value, which showed relationship between swimming speed, heart rate performance and recovery time at each swimming speed level.

Results

Fig. 3a and b show the relationship between swimming speed and endurance time by semi-log linear regression. There was a negative correlation between swimming speed and endurance. The swimming endurance time at 15 °C and 22 °C decreased in both the 1st and 2nd exercise, when the swimming speed levels were increased. The swimming endurance pattern was similar during the 1st and 2nd exercise at 15 °C and 22 °C (Figs. 3a and b). The comparison of the swimming endurance time in Figs. 4a and b showed no differences between the 1st and 2nd exercises at respective swimming speed levels for 15 °C and 22 °C. This was indicated by low residual between x-axis and y-axis at each plot data.

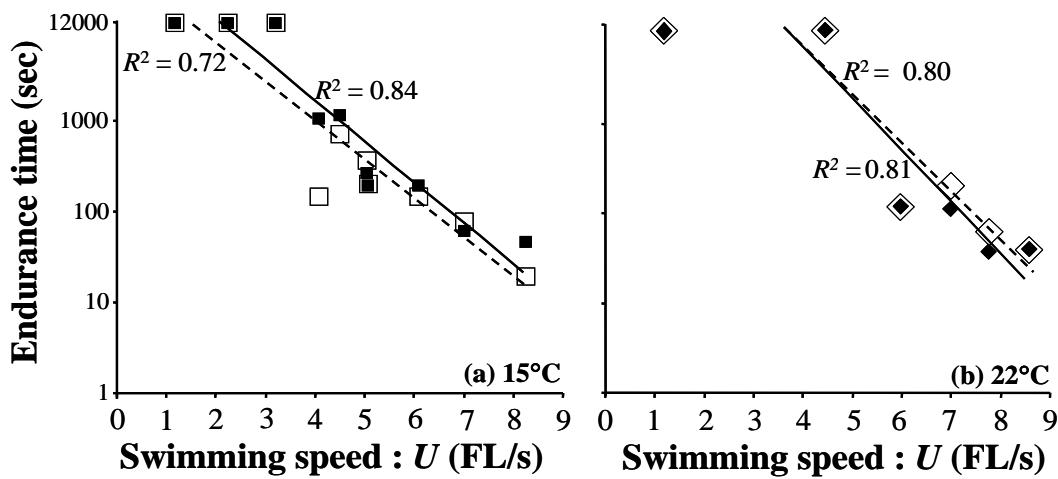


Fig. 3. Relationship between swimming endurance and speed ($FL \cdot s^{-1}$) at 15 °C (a) and 22 °C (b). Open marks indicated the 1st swimming exercise trial, and black marks were 2nd swimming exercise trial. Broken line was regressed in semi-log linear at the 1st swimming exercise trial and Solid line was at the 2nd swimming exercise trial.

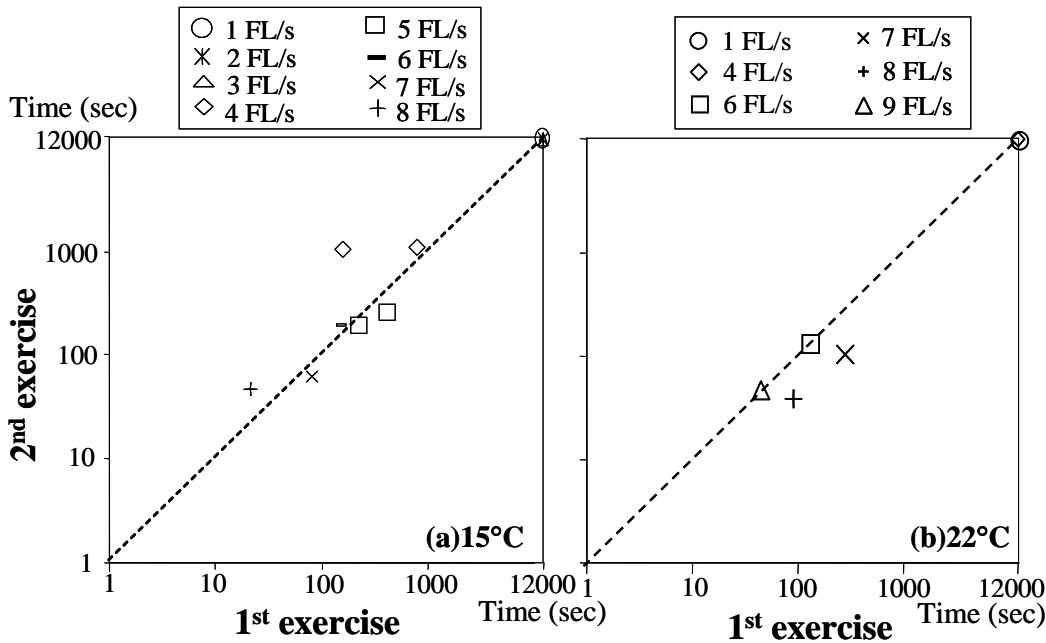


Fig. 4. Comparison between swimming endurance time at the 1st and 2nd swimming exercise trials for 15 °C (a) and 22 °C (b). Respective marks were represented for each swimming speed level and each fish trial.

The heart rate did not change from the 1st exercise to the 2nd exercise. The heart rate for the control was 38.3 ± 10.3 beats·min⁻¹ for 15 °C and 56.5 ± 13.1 beats·min⁻¹ for 22 °C when fish was swimming at sustained swimming speed of 1.1 to 2.2 FL·s⁻¹ (Fig. 5a and b). No fatigue was identified at these speeds, even during the 2nd swimming exercise. The heart rate increased to 60.0-63.6 beats·min⁻¹ for 15 °C and 176.2-192.8 beats·min⁻¹ for 22 °C at the vicinity of the maximum sustained swimming speed in the 1st and 2nd exercise trials respectively. The heart rate increased to reach the maximum value of 111.1-120.8 beats·min⁻¹ for 15 °C and 187.8-172.5 beats·min⁻¹ for 22 °C on average in 1st and 2nd exercise trials

respectively at the prolonged swimming speed level. The increasing trend of heart rate in relation to swimming speed had a similar pattern in the 1st and 2nd exercise trials at each swimming speed levels as shown in Fig. 5a and b. The comparison of the heart rate as shown in Fig. 6a and b, which were not different between 1st and 2nd exercise at each swimming speed level.

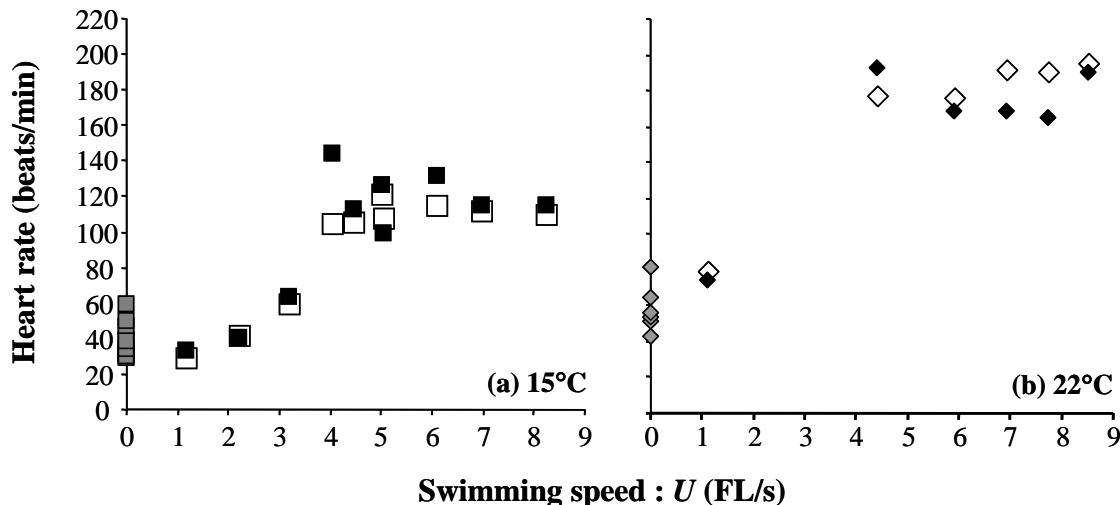


Fig. 5. Average heart rates according to swimming speed at the 1st and 2nd swimming exercise trials for 15 °C (a) and 22 °C (b). Gray marks were heart rate in control; open marks were heart rate at the 1st swimming exercise trial and black marks were heart rate at the 2nd swimming exercise trial.

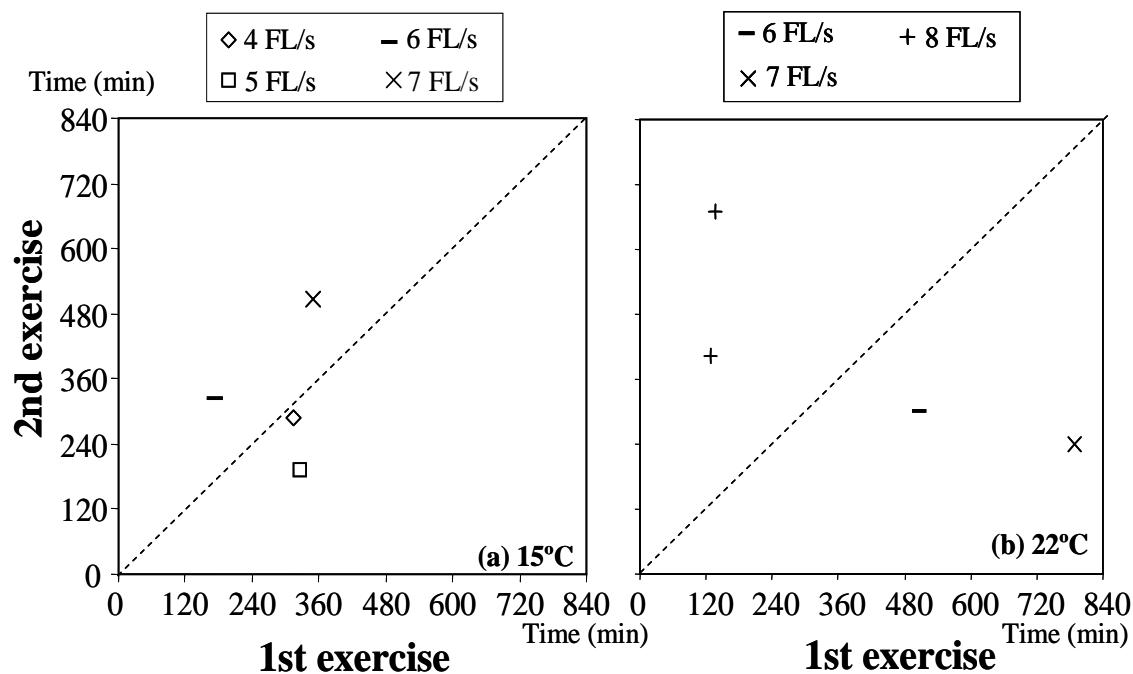


Fig. 6. Comparison between average heart rates at 1st and 2nd swimming exercise trials for 15 °C (a) and 22 °C (b). Respectively marks were represented in each swimming speed level and each fish trial.

Figs. 7a and b show that fish immediately recovered after swimming at sustained swimming speed. The post-exercise recovery time increased after swimming at maximum sustained and prolonged swimming speed. The pattern of recovery time was similar between the 1st and 2nd exercises at sustained and maximum sustained swimming speed. No change was observed between the 1st and 2nd recoveries after swimming at sustained and maximum sustained swimming speed at each water temperature. However, the recovery time pattern was different between the 1st and 2nd recovery at prolonged swimming speed. Figs. 8a and b show the 2nd recovery was independent on the 1st recovery at prolonged swimming speed range at each water temperature.

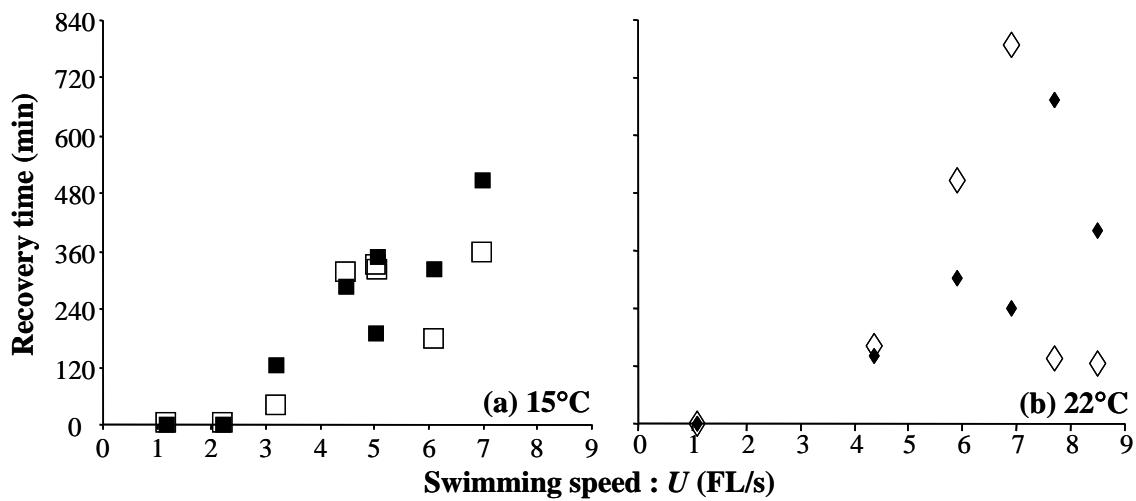


Fig. 7. Recovery time in relation to swimming speed at the 1st and 2nd swimming exercise trials for 15 °C (a) and 22 °C (b). Open marks were 1st post-exercise recovery, and black marks were 2nd post-exercise recovery.

Discussion

The swimming endurance after post-exercise recovery is important in the evaluation of the swimming performance of fish after escaping from the capture process by mobile fishing gears. This can help to explain the ability of fish to avoid and escape from the fishing gear, when they re-encountered gears or escaped from predators. The swimming endurance of jack mackerel did not change between the 1st and 2nd exercise trial, which implies that the fish had completely recovered during the 1st post-exercise recovery phase. In the previous study, the jack mackerel required the recovery time up to 543 min, after exercise at prolonged swimming speed (Nofrizal et al. 2009).

Heart rate of fish increased during swimming and then decreased when swimming ceased (Stevens and Randall 1967; Priede 1974; Korsmeyer et al. 1997). The ECG observation on the heart rate activities of jack mackerel did not increase at low speed of sustained swimming. The heart rate dramatically increased at the vicinity of the maximum sustained swimming speed (Nofrizal et al. 2008; 2009). Physiologically, this indicates that metabolic rate of jack mackerel is normal during exercise at sustained swimming speed levels.

Therefore, fish are able to keep swimming for their whole life as a daily activity without fatigue. The increment trend of heart rate was just the same between the 1st and 2nd exercise. The heart rate activities in the repeated exercise were not affected by the previous exercise at sustained and prolonged swimming speed after complete recovery. This illustrates that metabolic rate of the 1st and 2nd exercise is equal; as a result, fish have equal energy storage for swimming in both exercises. On the other hand, the fish could have completely remetabolized the energy storage during the 1st post-exercise recovery. This supported the fact that the heart rate activity was similar between 1st and 2nd swimming exercises.

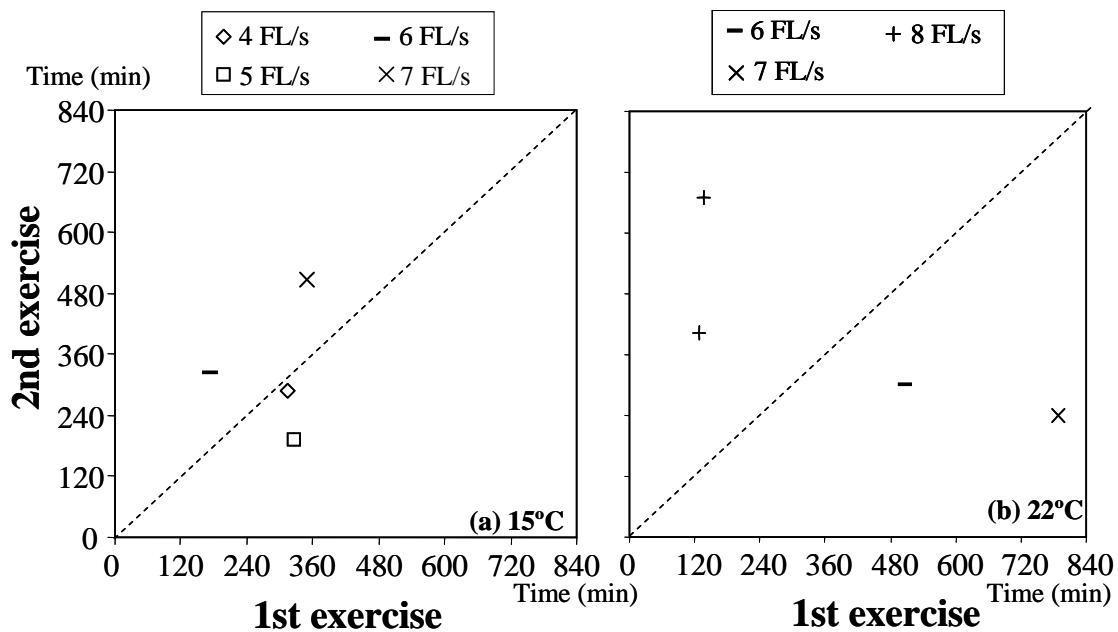


Fig. 8. Comparison between recovery time at the 1st and 2nd swimming exercise trials at prolonged swimming speed for 15 °C (a) and 22 °C (b). Respective marks representing each swimming speed level and each fish trial were denoted.

Under-water observation of the trawling capture process showed fish would swim until exhaustion with several swimming speed levels to maintain their position as long as possible to prevent falling back into the cod-end. The exhausted fish have less capability to swim and to avoid and escape from the fishing gear. Thus, fish will be accumulated and caught in the cod-end of the trawl. A previous study reported that recovery of the swimming muscle can take up to 24 hours following complete exhaustion (Nofrizal et al. 2009). During recovery period most of the lactic acid can remain in the fish muscle (Wardle 1978; Xu et al. 1993) and may be converted back to glycogen without leaving the muscle cells (Batty and Wardle 1979). However, recovery time of heart rate for jack mackerel was 103-543 min and was shorter than that of muscle recovery (Nofrizal et al. 2009). The fish recovered from the exhaustion shorter than 24 hr. In this case, the heart rate could be a key fatigue indicator related to swimming activities.

Independent functioning of the recovery time at the 1st and 2nd post-exercise recovery was examined by monitoring the ECG in each recovery phase. Thus, jack mackerel could survive if they did not encounter fishing gear during the recovery phase after escaping from a capture process or did not meet with a predator. However, Chopin and Arimoto (1995) stated that fishing gear types used for harvesting marine and fresh water fish may cause a range of physical damages by injuries, stress reactions and mortalities that can occur during the capture and escape process. Therefore, Chopin and Arimoto (1995) suggested that improving selectivity without reducing damage or stress incurred during capture and escape may be the most appropriate way of protecting immature fish. The smaller immature fish have poorer swimming performance than bigger fish in terms of maximum swimming speed for jack mackerel *Trachurus japonicus* (Xu et al. 1988) and sand flathead *Platycephalus bassensis* (Yanase et al. 2007). Thus, smaller fish have lower capability to avoid and escape from the gear during the capture process. Hence, the excluder device would be helpful to release the immature fish before they become completely exhausted. This study indicated that the swimming performance of fish was not impacted after prior exercise if they were allowed to have complete recovery. Therefore it can be concluded that the escaping fish from the capture process would have the same capability to avoid and escape from the gear if re-encountered after they have completely recovered from the previous capture-related exhaustion.

References

An, Y. and T. Arimoto. 1994. Avoidance response of jack mackerel to a strobe light barrier. Nippon Suisan Gakkaishi 60:713-718.

An, Y. and T. Arimoto. 1997. Heart rate change of jack mackerel by strobe light frequency. Nippon Suisan Gakkaishi 63: 3-9.

Batty, R.S. and C.S. Wardle. 1979. Restoration of glycogen from lactic acid in the anaerobic swimming muscle of plaice, *Pleuronectes platessa* L. Fish Biology 15:509-519.

Chopin, S.F. and T. Arimoto. 1995. The condition of fish escaping from fishing gear - a review. Fisheries Research 21:315-327.

He, P. and C.S. Wardle. 1988. Endurance at intermediate swimming speeds of Atlantic mackerel, *Scomber scombrus* L., herring, *Clupea harengus* L., and saithe, *pollachius virens* L. Fish Biology 33:255-266.

Ito, H., S. Akiyama and T. Arimoto. 2003. Heart rate change during exercise and recovery for carp *Cyprinus carpio*. Nippon Suisan Gakkaishi 69:192-196.

Korsmeyer, K.E., N.C. Lai, R.E. Shadwick and J.B. Graham. 1997. Heart rate and stroke volume contributions to cardiac output in swimming yellow fin tuna: response to exercise and temperature. Experimental Biology 200:1975-1986.

Nofrizal, K. Yanase and T. Arimoto. 2008. Swimming exercise and recovery for jack mackerel *Trachurus japonicus*, monitored by ECG measurements. Proceedings of the 5th World Fisheries Congress (CD-ROM) 1b:0028-396.

Nofrizal, K. Yanase and T. Arimoto. 2009. Effect of temperature on the swimming endurance and post-exercise recovery of jack mackerel *Trachurus japonicus*, as determined by ECG monitoring. Fisheries Science 75:1369-1375.

Priede, I.G. 1974. The effect of swimming speed activity and section of the vagus nerves on the heart rate in rainbow trout. *Experimental Biology* 60:305-319.

Stevens, E.D. and D.J. Randall. 1967. Changes in blood pressure, heart rate and breathing rate during moderate swimming activity in rainbow trout. *Experimental Biology* 46:307-315.

Wardle, C.S. 1978. Non-release of lactic acid from anaerobic swimming muscle of plaice *Pleuronectes platessa* I.: A stress reaction. *Experimental Biology* 77:141-155.

Wardle, C.S. 1993. Fish behaviour and fishing gear. In: The behaviour of teleost fishes, 2nd edition (ed. T. J. Pitcher), pp. 609-643. Chapman and Hall, London.

Xu, G., T. Arimoto and M. Inoue. 1988. The measurements of swimming speed in jack mackerel *Trachurus japonicus*. *Nippon Suisan Gakkaishi* 54: 1493-1497.

Xu, G., T. Arimoto and M. Inoue. 1993. Red and white muscle activity of the jack mackerel *Trachurus japonicus* during swimming. *Nippon Suisan Gakkaishi* 59:745-751.

Yanase, K., S. Eayrs and T. Arimoto. 2007. Influence of water temperature and fish length on the maximum swimming speed of sand flathead, *Platycephalus bassensis*: Implications for trawl selectivity. *Fisheries Research* 84:180-188.