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# Swimming Exercise Impact on Cardiac Activities of Jack Mackerel (*Trachurus japonicus*) and Tilapia (*Oreochromis niloticus*) by Electrocardiograph Measurement

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## ABSTRACT

Ninety jack mackerels (18.68±0.90 cm, Fork Length (FL) (average ± S.D., *n* = 90) and twenty nile tilapias (14,80±1,20 cm, *n* = 20) were forced to swim in swimming channel of flume tank at various swimming speed level as 20.40-147.00 cm/s, which corresponded to 1.09-9.12 FL/s at 10, 15 and 22°C respectively for jack mackerel and 5.97-47.73 cm/s, which corresponded to 0.37-3.85 FL/s for nile tilapia. The heart rate was measured by impleting a pair of electrode at pericardial cavity region of both fish, which was conected to digital oscilloscope via an bio-amplifier. The highest stress level was occurred at vicinity of the maximum sustained and prolonged swimming speed. This indicated that the heart rate of jack mackerel was increasing steadily to reach 3.60 times greater than control value for 10°C, 4.03 for 15°C, and 4.20 for 22°C in prolonged swimming speed. The incremental of heart rate was reach 3.85 times greater than control value at 25°C for tilapia. The recovery time for post-exercise was monitored to be the longest (up to 543 min) at these swimming speed levels for jack mackerel. The incremental of heart rate in relation to swimming speed level are discussed deeply in this paper.

***Keywords:*** *Electrocardiograph (ECG), exercise, heart rate, jack mackerel, nile tilapia.*

## INTRODUCTION

In the capture process of active sampling gear such as, trawl, purse seine, and seine net, most of target and non-target fishes are forced to swim as fast and as longest as possible to avoid and escape in front and inside of the gear. Therefore, the respective swimming performances of both target and non-target fish can be the key factor in determining the selectivity and efficiency of active fishing gears (He, 1991; Winger *et al*., 1999; Wardle, 1986; Nofrizal *et al*., 2009; Nofrizal and Ahmad 2015). This is supported by the fact that these fishes are only capable of swimming at or below their maximum sustained swimming speed for relatively longer time duration (Webb, 1994; Coughlin, 2002). In this condition, the fish is getting fatigue at higher swimming speed during sampling capture process by mobile fishing gears.

The swimming activity of fish is influenced by respiratory and metabolic processes, which are reflected by the heart rate as the pumping mechanism of the blood circulation system in the body. The heart rate represents the gas exchange and chemical processes to metabolize the energy use when a fish is swimming. All together can represent or reflect the physiological condition of fish. The heart rate can be also an index for accurate prediction of oxygen consumption at different levels of exercise and recovery (Clark *et al*., 2006). Physiologically, the heart rate represents fish condition including muscle exhaustion due to swimming activity at the higher swimming speed (Nofrizal and Arimoto, 2011; Nofrizal, 2014). The fish that was caugth by the active fishing gear can not use imediately in behavioral experiment observation, due to the different patterns for behavioral analysis. Therefore, acclimations time is required for fish sampled before experiment. This paper presented how the cardiac activities of fish during swimming to avoid the fishing gear during capture process, which was examined through the heart rate monitoring as an indicator to determine physiological condition of fish based on swimming speed level. Therefore, a simulation experiment was conducted

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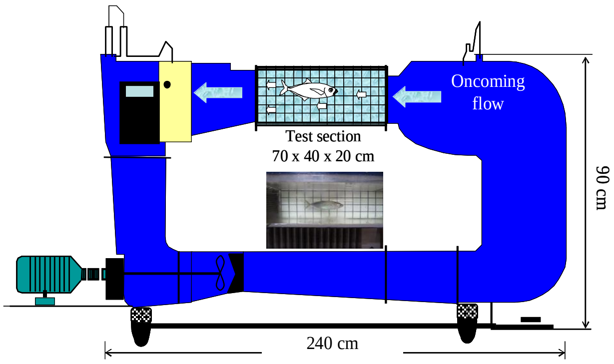
in the flume tank, which is to reflect the fish stress and fatigue during swimming to avoid the fishing gear in capture process.

## MATERIAL AND METHODS

Experimental fish Jack mackerel (18.6 ± 0.9 cm FL; *n* = 90) and nile tilapia (14,80±1,20 cm, *n* = 20) were kept in acclimation tank for more than a week to avoid stress on the specimen in this experiment. Water temperature in the acclimation tank was set as desire temperature in experiment condition, such as 10, 15 and 22$^0$C for jack mackerel and 28$^0$C for nile tilapia. The fish were fed on fish meal pellet every day during the periods of experimental phase.

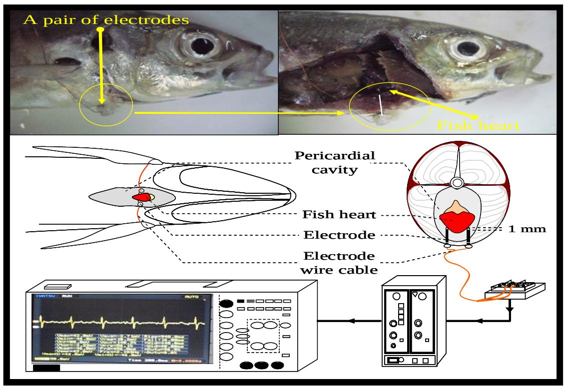
Flume tank and ECG observation A flume tank (West Japan Fluid Engineering Laboratory, PT-70) was used in this study for forcing fish to swim against given flow speeds in the test section, 70 cm in length by 30 cm in width by 20 cm in depth, with a steady water flow (Fig.1) (Nofrizal, 2009; Nofrizal *et al*., 2009; Nofrizal and Arimoto, 2011; Nofrizal, 2014; Nofrizal and Ahmad, 2015). The swimming speed of fish is equal to the given flow speed of the flume tank, when the fish was swimming to maintain their position in the test section of flume tank. The water temperature in the flume tank was continuously monitored to maintain the desired temperature as 10, 15, 22°C for jack mackerel and 28°C for nile tilapia, using a digital thermo-controller (REI-SEA, TC-100, Japan) (Nofrizal *et al*., 2009; Nofrizal 2009; Nofrizal and Arimoto, 2011; Nofrizal, 2014; Nofrizal, 2015).




Source: Nofrizal *et al*., 2009; Nofrizal 2009; Nofrizal and Arimoto, 2011
**Figure 1.** Experimental apparatus for swimming endurance and ECG measurement.

In electro-cardiographic (ECG) monitoring, a pair of electrodes was implanted at the pericardial cavity of jack mackerel and nile tilapia (Figure 2), under anesthetizing by FA100 for 15–20 minutes for jack mackerel and extract. The bi-polar electrodes were made of an enamel-insulated tungsten pin (MT Giken), 15 mm length and 0.2 or 0.3 mm in diameter. The outer insulation for the electrode on both sides of the tips (1 mm) was removed. The one side was connected to a copper wire (Tsurumi Seiki, T-GA XBT cable) of 110 cm length and was covered by instant glue (Aron Alpha, Toagosei). The other end of the wire was connected to a digital oscilloscope (DS-5102, Iwatsu) via an amplifier (Bioelectric Amplifier AB-632J, Nippon Kohden) as shown in Figure 2 (Nofrizal, 2009; Nofrizal *et al*., 2009; Nofrizal and Arimoto 2011). After the subsequent recovery of three hours from anesthesia, the heart rate of the fish was individually monitored in still water for 10 minutes. The data of heart rate (beat/min) were averaged, and this was used as the control heart rate in order to compare as the differences with the heart rate during exercise at a given flow speed each individual as 20.40, 39.30, 55.40, 74.30, 93.10, 112.00, 128.10, 147.00 and 160.40 cm/s, which are corresponded to 1.09-9.12 FL/s for jack mackerel. While, the given flow speed was 5.97, 9.19, 13.83, 17.67, 23.56, 29.33, 35.31, 41.67, 47.73 and 55.64 cm/s, its corresponded to 0.37-3.85 FL/s.

Measurement of heart rate during exercise was 200 minutes or until fatigue at each swimming speed, which was a duration time until the fish discontinue swimming by thrusting against the downstream panel, or determined as 200 min (He and Wardle, 1988; He, 1991; Nofrizal *et al*., 2009). In this study, the swimming speed was classified in four levels (Nofrizal *et al*., 2009). The sustained speed is the low speed of swimming, where fish could swim more than 200 minutes of the swimming endurance trial. The sustained speed was ≤ 2.4 FL/s at 10ºC, ≤ 3.4 FL/s at 15ºC and ≤ 3.2 FL/s at 22ºC (Nofrizal *et al*., 2009). The maximum sustained speed is the highest level of sustained speed, where anaerobic white muscle affiliated into aerobic red muscle activities for swimming, and than the swimming endurance decreased and terminated by fatigue within 200 minutes (Nofrizal, 2009; Nofrizal *et al*., 2009; Nofrizal, 2014; Nofrizal and Ahmad 2015). At the previous study showed that the lower temperature was lower estimation of the maximum sustained swimming speed, which is the maximum sustained swimming speed was 2.4 FL/s for 10ºC, 3.4 FL/s for 15ºC and 3.2 FL/s for 22ºC (Nofrizal *et al*., 2009). The prolonged speed, it was higher swimming speed level than maximum sustained speed in few minutes swimming endurance trial. The range of prolonged speed was 2.4-8.0 FL/s at 10 ºC, 3.4-10.3 FL/s 15 ºC and 3.2-9.6 FL/s at 22ºC (Nofrizal *et al*., 2009). Finally, the burst swimming speed is the highest swimming speed level in few seconds and defined (less than 15 seconds) in this paper. In previous study Nofrizal *et al*. (2009) the burst swimming speed of jack mackerel was estimated ≥ 8.0 FL/s at 10ºC, 10.3 FL/s at 15ºC and 9.6 FL/s at 22 ºC.




Source: Nofrizal *et al*., 2009; Nofrizal 2009; Nofrizal and Arimoto, 2011; Nofrizal, 2015
**Figure 2.** Position of the pair electrodes used to monitor the heart rate. The pictures were took after experiment was conducted.

**Data Analysis.** Increment of heart rate was analyzed by the relative heart rate at respective swimming speed level. The relative heart rate is the average of the heart rate in exercise divided with average of heart rate in control (An and Arimoto, 1997; Ito *et al*., 2003; Nofrizal, 2009). Increment of heart rate at respective swimming speed level examined to the physiological stress level index of fish during swimming.

## RESULT

**Heart Rate in Control.** Figure 3a and b show oscilloscope display for the ECG pattern of jack mackerel, which is similar to those of mamals and humans. The ECG pattern shows blood circulation in the fish body, which is pumped by heart. The *P-wave* shows the depolarization of the atrium, which is a process the blood pumped into the ventricle. *QRS* shows the ventricle depolarization, which

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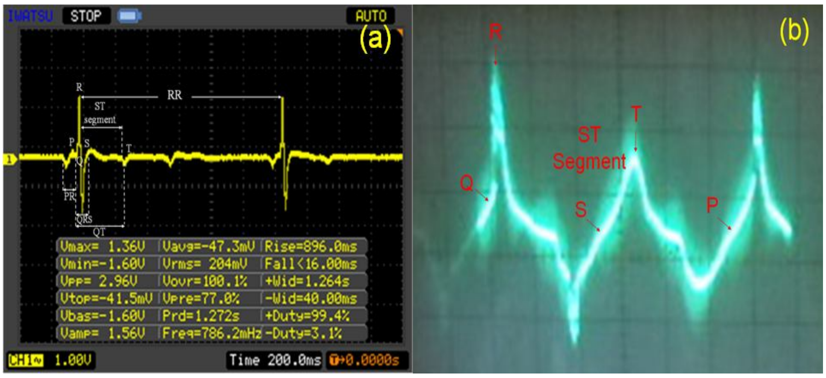
is a process the blood pumped through arteries and capillaries outspread to all the body parts. *ST segment* shows a process of the ventricular redepolarization, and *PR* shows the interval time of the threshold of atrial depolarization to the threshold of ventricular depolarization. *QRS* shows the duration of ventricular muscle depolarization process. *QT* shows the duration of ventricular depolarization and repolarization process, and *RR* shows the duration of the ventricular cardiac cycle, while *PP* shows the duration of the atrial cycle (Namba, 1996; Nofrizal *et al*., 2009). The blood circulation process are going to be faster or slower depend on swimming speed level (Nofrizal *et al*., 2009; Nofrizal, 2014).




Source : Nofrizal, 2009; Nofrizal *et al*., 2009; Nofrizal, 2015.

**Figure 3.** ECG pattern of fish specimen during measurement; (a) ECG pattern of jack mackerel (*Trachurus japonicus*), and (b) ECG pattern of nile tilapia (*Oreochromis niloticus*).

The heart rate during the control phase could be affected by the water temperature. Fig 4 shows that the range of the heart rate activity decreased at the lowest temperature, it was 13-37 beats/min for 10°C, and 27-71 beats/min at medium temperature as 15°C. Meanwhile, the heart rate was high increased as 42-95 beats/min for 22°C. The average of heart rate represents the increment of heart rate activity, which follows water temperature changes as shows at Figure 4. The average of heart rate was 25.3 ± 5.7 (Average ± STDEV) beats/min at 10°C, and increase as 38.9 ± 11.1 beats/min at 15°C, and 67.2 ± 13.2 beats/min at 22°C. While, the average of heart rate of nile tilapia was 46.8 ± 2.85 beats/min at 28°C. The standards deviations of heart rate above showed the variation heart rate in control at each temperature, which the variation of heart rate was higher at the higher temperature.

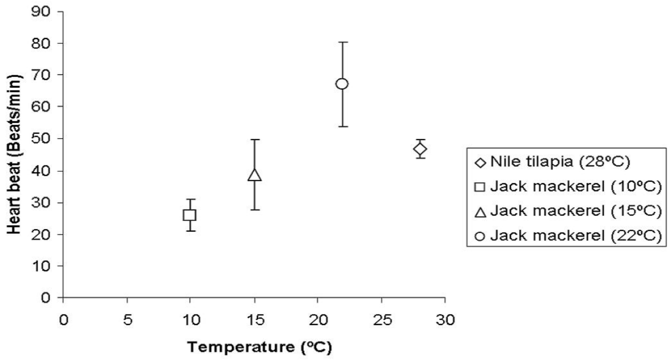
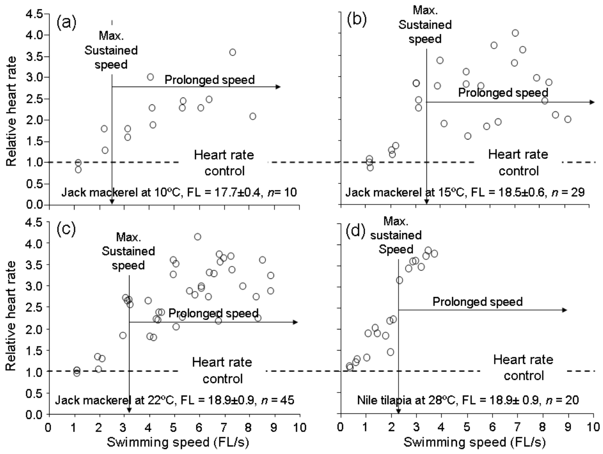



**Figure 4.** Heart rate in control at 10, 15 and 22ºC . The raw data source from Nofrizal *et al*.,(2009) and Nofrizal (2014).

**Heart rate in swimming exercise.** Figure 5a, b, c and d show the result of the relative heart rate analysis according to the swimming speed in each temperature tested. At the sustained swimming speed as 1 FL/s, the relative heart rate was examined to be 1.0 all temperatures, which means that the heart rate was not change during swimming exercise tested. Increment of heart rate was occurred at the vicinity of maximum swimming speed. As show at Figure 5a, the relative heart rate was increased in average as 1.55 times greater than control value at vicinity of the maximum sustained swimming speed as 3 FL/s at 10ºC. At the higher temperatures as 15 and 22ºC, the heart rate was highly increased as 2.80 and 2.68 times than control value at vicinity of maximum swimming speed (3 FL/s)(Figure 5b and c).




*Source*: Nofrizal (2009); Nofrizal (2014)
**Figure 5.** Relationship between relative heart rate and swimming speed (FL/s); (a) jack mackerel at 10ºC, (b) jack mackerel at 15ºC, (c) jack mackerel at 22ºC and (d) nile tilapia at 28ºC. Broken line is heart rate in control.

At the prolonged as up to 3 FL/s and burst swimming speed as up to 8 FL/s, the relative heart rate was dramatically increased than control value at each temperature. The relative heart rate was increased as 2.35 times greater than control value, and can reach as a maximum 3.60 times greater than control value at 10 ºC (Figure 5a). At 15 ºC, the relative heart rate was increased as 2.71 times, which can reach as a maximum 4.00 times (Figure 5b) and the relative heart rate was higher increased at warmer temperature, which was 2.86 times and reached as a maximum 4.20 times greater than control value for 22ºC (Figure 5c). While, the relative heart rate was increased as 1.08 times greater than control value, and can reach 3.85 times greater than control value at 28ºC for nile tilapia (Figure 5d).

## DISCUSSION

Temperature was significantly influenced the heart rate in control. Heart rate was increase at warmer temperature for jack mackerel (Nofrizal 2009; Nofrizal *et al*., 2009). Its also influenced recovery phase after swimming activity (Nofrizal and Arimoto, 2011). Previous study was reported that the temperature also influence swimming endurance of fish. The swimming endurance of fish was longer at warmer temperature and decrease at the lower temperature (Nofrizal *et al*., 2009). Heart rate in control was varied at each temperature (Figure 4), which is affected by autonomic nervous system (sympathetic nervous system) of individual condition of the fish. Meanwhile, increment of heart rate in vicinity of the maximum sustained swimming speed and prolonged speed expressed high stress and exhaustion at those swimming speed levels.

At the sustained swimming speed (1 FL/s), the heart rate activity did not change much with control value at respective all water temperatures. At this condition, fish can swim as long without significant physiologyical change process. The maximum sustained swimming speed, prolonged and burst speed occurred during capture sampling process by the mobile fishing gears such as trawl. Modern trawls are made in many sizes to allow different types of fishing boat to tow them at a maximum speed: between 3 and 4 knots or 154.2 and 205.6 cm/s when using full power (Wardle, 1993). These towing speeds corresponded to swimming speeds of 8.3 and 11.1 FL/s for the fish used in this study. Thus, fish swims in prolonged or burst swimming speed, to avoid and escape during the capture process. Chopin and Arimoto (1995) stated that the fish swimming in the codend of the trawl during capture process will be subjected to its serve exercise. This evokes mortalities, which have been attributed to stress associated with various capture stressors even if the fish could escape from capture. This study demonstrated that the magnitude of the stress given to the fish during exercise at faster speed range than 3 FL/s swimming speeds was scaled by the heart rate activity for an amount of time. This situation happens when the fish was encountering by the mobile fishing gear, where the heart rate of fish high increased at prolonged and burst speed as show at 5a, b and c. In this condition, the fish are under stress and tachycardia even if they could escape from the gears. Therefore, it takes substantial time for those fish to recover from fatigue.

The heart rate activity of jack mackerel increases gradually to follow the swimming speed level (Nofrizal, 2009; Nofrizal *et al*., 2009; Nofrizal and Arimoto, 2011). These increases in order to fulfill oxygen demand in the blood required for myotomal muscle to intensively operate through aerobic metabolic pathway. The incremental pattern of the heart rate for jack mackerel during swimming exercise was similar to the rainbow trout, *Salmo gairdneri* (Priede, 1974). Fish consume extra energy in response to the increased swimming speed, and require to increase the metabolic rate in order to reform the lost energy. Physiologically, the heart rate activity associates with metabolic and respiratory process when the fish swimming. Thus, heart rate serves as several functions, such as pumping of blood, nutrition and oxygen circulation for a biochemical process in the fish body to re-metabolize nutrient to be transfered as energy for swimming. This process is getting faster or slower based on the magnitude of exercise.

Previous study showed that, no recovery time is required at lower speed of sustained swimming speed. It was required at vicinity of the maximum sustained swimming speed for each temperature (Nofrizal *et al*., 2009). As Figure 5a, b and c show that no stress and fatigue occurs at lower speed level. However, fatigue and stress occurred at higher speed level such as maximum sustained, prolonged and burst swimming speed. At the prolonged swimming speed, and the higher temperature resulted in a longer recovery time requirement (Nofrizal *et al*., 2009). In the case of 5-7 FL/s for 22°C, the heart rate recovery to the control level took 103-543 min (Nofrizal, 2009). Cooke *et al*., (2004) reported that, laboratory cardiac parameters of the largemouth bass *Micropterus salmoides*, shows less variable patterns at 13-25°C, where the peak heart rate was recorded during the prolonged swimming exercise at various speed levels and it took about 135 minutes for subsequent recovery. This result shows that, fish was stressed and fatigued, when chased by the gear, due to severe swimming exercise in higher speed during sampling process. Therefore, fish is required for the longer time for recovery if the fish will be used as sample for an experiment of the swimming behavior and performance. Therefore, adaptation or acclimation is recomannded up to nine hours or at least the heart rate is stable as control level (Nofrizal *et al.*, 2009; Nofrizal and Arimoto, 2011), as preparatory for swimming behavior and performance experiment in case for jack mackerel and nile tilapia. Furthermore, this paper is expected to contribute information for a sample method and experiment procedure for studying the fish swimming behavior toward fishing gear.

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