

Effect of Wearing Clothes on Oxygen Uptake and Ratings of Perceived Exertion while Swimming

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Abstract For a comparative study between swimming in swimwear (control-sw) and swimming in clothes (clothes-sw), oxygen uptake ($\dot{V}O_2$) and ratings of perceived exertion (RPE) were measured. The subjects were six male members of a university swimming team. Three swimming strokes - the breaststroke, the front crawl stroke and the elementary backstroke - were applied. With regards to clothes-sw, swimmers wore T-shirts, sportswear (shirt and pants) over swimwear and running shoes. In both cases of control-sw and clothes-sw, the $\dot{V}O_2$ was increased exponentially with increased swimming speed. The $\dot{V}O_2$ of the subjects during the clothed tests did not exceed 1.4 times of that in the case of control-sw at swimming speeds below 0.3 m/s. As swimming speeds increased, $\dot{V}O_2$ difference in both cases increased. Consequently, $\dot{V}O_2$ in the clothed tests was equal to 1.5-1.6 times and 1.5-1.8 times of that in the swimwear tests at speeds of 0.5 and 0.7 m/s, respectively. At speeds below 0.6 m/s in clothes-sw, the breaststroke showed lower $\dot{V}O_2$ than the front crawl stroke, and the elementary backstroke showed higher $\dot{V}O_2$ than the other two swimming strokes. RPE increased linearly with %peak $\dot{V}O_2$. In addition, any RPE differences among the three swimming strokes were not shown in the control-sw tests. At an exercise intensity above 60%peak $\dot{V}O_2$, clothed swimmers showed slightly higher RPE in the front crawl stroke compared to that in the two other swimming strokes. *J Physiol Anthropol* 19 (4): 167-173, 2000 <http://www.jstage.jst.go.jp/en/>

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Introduction

To prevent drowning accidents, swimming in clothes (clothes-sw) has received attention recently. It is generally

known by experience that clothes-sw is more difficult than swimming in swimwear (control-sw). However, the exercise intensity of clothes-sw has not been fully investigated.

Tsubakimoto et al. (1992), pointed out that both the swimming distance for 10 minutes and the heart rate (HR) measured after those 10 minutes of swimming in clothes did not reach as far or as high as those of control-sw. In another study which investigated the effect of clothing types on HR and swimming speeds, which were measured after having subjects swim 25 and 50 m lanes at full strength, Choi et al. (1994; 1999) concluded that the breaststroke was a more suitable swimming stroke for clothes-sw than front crawl stroke or back crawl stroke.

Tsubakimoto et al. (1992) and Choi et al. (1994; 1999) investigated the effect of clothing types on swimming based on the HR value which was measured after the subjects' strength had been pushed to their individual limits. Although there was a correlation between HR and $\dot{V}O_2$ in swimming (Holmér, 1974; Kurokawa et al., 1984), $\dot{V}O_2$ was a more reasonable scale for evaluating the exercise intensity of a given swimming speed because of individual differences in HR. Furthermore the energy cost in swimming increased exponentially with the increase in swimming speed (Andersen, 1960; Holmér, 1974; Sugiyama and Katamoto, 1992). Therefore, for an accurate study on the effects of clothing on swimmers, a systematic investigation into the various kinds of swimming speeds is required. Moreover, it is empirically known that the front crawl stroke produces severe local fatigue of the shoulder in comparison with the breaststroke and the back crawl stroke in clothes-sw. For this reason, considering the practical application of clothes-sw, a corresponding relationship between $\dot{V}O_2$ and ratings of perceived exertion (RPE) should be examined.

With respect to the preceding aspects, this study focused on comparing the $\dot{V}O_2$ of control-sw and clothes-sw. The purpose of this study was also to determine the effects of clothing on a swimmer's RPE.

Methods

Subjects

The subjects of the experiment were six male members of a university swimming team. Their swimming abilities were at a mid-range university swimming team level. Table 1 shows their anthropometric data and their best swimming records.

Experimental procedures

On the day before the experiment day, the subjects practiced 5 different levels of swimming speeds from 0.3 to 1.1 m/s in order to regulate each subject's swimming speeds. At the same time, they swam at a set speed by going with a researcher who was accustomed to pace-walking and following his instructions as to swimming speeds.

On the day of the experiment, the subjects rested by sitting on chairs on land for a half hour and then front-floated under water for five minutes with a gas collection apparatus consisting of a type of snorkel which was fitted over their heads with a metal headband. Then they performed one minute warm-up for each swimming speed, i.e. 0.3, 0.5 and 0.7 m/s. After checking if HR had almost returned to the resting level, the subjects were asked to swim a ring-shaped 126 m course in a 50 m pool to measure $\dot{V}O_2$. The swimming speed was increased by 0.2 m/s starting from 0.3 m/s until levelling off of $\dot{V}O_2$ and a respiratory exchange ratio over 1.1 were noted. At each trial, the subjects swam for five minutes. A 5-10 minute break was allowed after the completion of each trial. The mean swimming speed was calculated by dividing swimming distances by time. The error proportion was limited to $\pm 2\%$. When the experiments were carried out, the water temperature was 28-30°C and the air temperature was 29-33°C.

The three swimming strokes, consisting of the breaststroke, the front crawl stroke and the elementary backstroke were applied in both cases of control-sw and clothes-sw. These three swimming strokes have generally been used in teaching clothes-sw. The elementary

backstroke is an intermediate motion between the back crawl stroke and the breaststroke. In performing the elementary backstroke the subject lay on his back and did the stroke motions of the back crawl stroke with both arms at the same time and the recovery motions of arms were done under water. However, there were kick motions occurring during the breaststroke with the subject's legs.

Subjects wore T-shirts, sportswear (shirt and pants) over swimwear and running shoes in the swimming in clothes tests. The T-shirts and sportswear used in the experiment were made of 100% cotton and 100% polyester, respectively. The order of the trials conducted was random for both control-sw and clothes-sw, and only one swimming stroke per day was applied.

Gas expired was collected in a Douglas bag for one minute starting on the fourth minute after starting motions of both front-float and swimming. Expired gas for less than 30s was not adapted as analysis data. A mass spectrophotometer (Perkin-Elmer model 1100), that had been calibrated with gases previously analyzed by the micro-Scholander technique, was used for analysis of O_2 and CO_2 in expired gas. A calibrated dry-gas meter (Shinagawa Co. model DS-15A-T) was utilized for measuring the gas volume. To correlate the swimming speeds to RPE at all swimming speeds, subjects were surveyed as soon as they finished swimming. RPE-ratings were scored using Japanese expressions from Onodera and Miyashita (1977) according to Borg's RPE scale (Borg, 1973) which is composed of 15 steps.

Statistics

The equation of the relationship between %peak $\dot{V}O_2$ and RPE was made by the following steps (Ueda et al., 1993). First, a functional formula of the first degree was found by putting each $\dot{V}O_2$ and RPE value into a linear regression equation. There was a very high correlation ($r \geq 0.9$) between $\dot{V}O_2$ and RPE. Next, the RPE of each subject was calculated by putting $\dot{V}O_2$ of per 10%peak $\dot{V}O_2$ on this equation of linear regression. Finally, the equation of linear regression between %peak $\dot{V}O_2$ and RPE of all the subjects during each swimming stroke was found in the least squares method.

Table 1 Anthropometric data and best records of the subjects

Subject	Age (years)	Height (cm)	Weight (kg)	Best record (sec)	
				Front crawl stroke	Breaststroke
A.H	19.5	180.9	82.3	53.9	55.1
H.S	18.5	179.0	76.5	63.1	75.4
T.H	22.6	188.4	76.8	60.3	72.8
T.T	20.0	183.9	77.5	58.8	60.1
H.Y	20.1	168.7	62.1	57.6	57.4
M.M	19.1	173.3	70.6	54.5	59.0
Mean	20.0	179.0	74.3	58.0	63.3
SD	1.4	7.1	7.0	3.5	8.6

One-way ANOVA and multiple comparison tests using the Tukey method were utilized. The level of significance was 5 and 1%.

Results

Figure 1 shows $\dot{V}O_2$ in relation to increasing speeds during the breaststroke in control-sw and clothes-sw. The $\dot{V}O_2$ of the subjects increased exponentially with increased speed in both cases. When the speed was zero or in front-float condition, there was no difference between the two. However, the difference between the two increased with speed, so that the $\dot{V}O_2$ in the clothed tests was 1.4, 1.5 and 1.7 times that in the swimwear tests at speeds of 0.3, 0.5 and 0.7 m/s, respectively ($p < 0.05$). The levelling off of $\dot{V}O_2$ was verified by clothes-sw at a speed of 0.7 m/s and in control-sw at a speed of 0.9 m/s.

Figure 2 shows $\dot{V}O_2$ in relation to increasing speeds during the front crawl stroke in control-sw and clothes-sw. There was a similar tendency between the front crawl stroke and the breaststroke. The $\dot{V}O_2$ in the clothed tests showed 1.4, 1.6 and 1.8 times of that in the swimwear tests at the speed of 0.3, 0.5 and 0.7 m/s, respectively ($p < 0.05$).

Figure 3 displays the $\dot{V}O_2$ in relation to increasing speeds during the elementary backstroke in control-sw and clothes-sw. The elementary backstroke was also equivalent to the other two swimming strokes. The $\dot{V}O_2$ in the clothed tests were 1.4, 1.6 and 1.8 times that in the swimwear test at speeds of 0.3, 0.5 and 0.7 m/s, respectively ($p < 0.05$).

Figure 4 shows $\dot{V}O_2$ in relation to speed during the

breaststroke, the front crawl stroke and the elementary backstroke in control-sw. The $\dot{V}O_2$ of subjects during the breaststroke exceeded that of the front crawl stroke at speeds from 0.7 to 0.9 m/s ($p < 0.01$ at 0.9 m/sec). The $\dot{V}O_2$ of subjects during the elementary backstroke was higher than the other two swimming strokes at all speeds below 0.9 m/s ($p < 0.05$). The levelling off of the $\dot{V}O_2$ occurred at speeds between 0.9 and 1.1 m/s and there were no differences in peak $\dot{V}O_2$ among the three swimming strokes.

Figure 5 shows $\dot{V}O_2$ in relation to increasing speeds during the breaststroke, the front crawl stroke and the elementary backstroke in clothes-sw. In this case, the intersection of the breaststroke and the front crawl stroke occurred at the speed of 0.6 m/s. At swimming speeds under 0.6 m/s, the $\dot{V}O_2$ of the breaststroke was lower than that of the front crawl stroke ($p < 0.05$). The $\dot{V}O_2$ of the subjects during the elementary backstroke was higher than those of the two other swimming strokes at speeds below 0.7 m/s. The difference between the $\dot{V}O_2$ of the elementary backstroke and that of the breaststroke was significant ($p < 0.01$). At speeds from 0.7 to 0.9 m/s, levelling off of $\dot{V}O_2$ occurred, but peak $\dot{V}O_2$ during the breaststroke (48.6 ml/kg/min) and the elementary backstroke (46.9 ml/kg/min) were 10.3 and 7.0% higher than that of the front crawl stroke, respectively.

The equations of linear regression between %peak $\dot{V}O_2$ and RPE during the control-sw tests and the clothed tests are expressed in Figs. 6 and 7, respectively. There were no significant differences among RPE in the three swimming strokes in either the swimwear tests or the

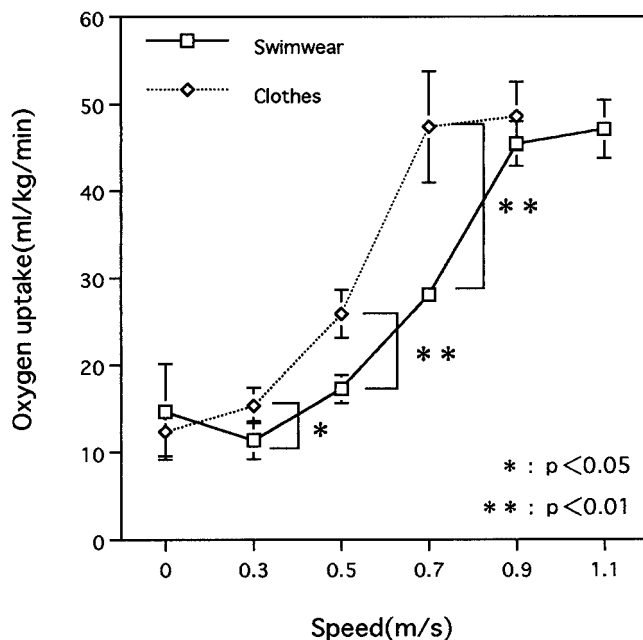


Fig. 1 $\dot{V}O_2$ in relation to speed during the breaststroke swimming in swimwear and in clothes.

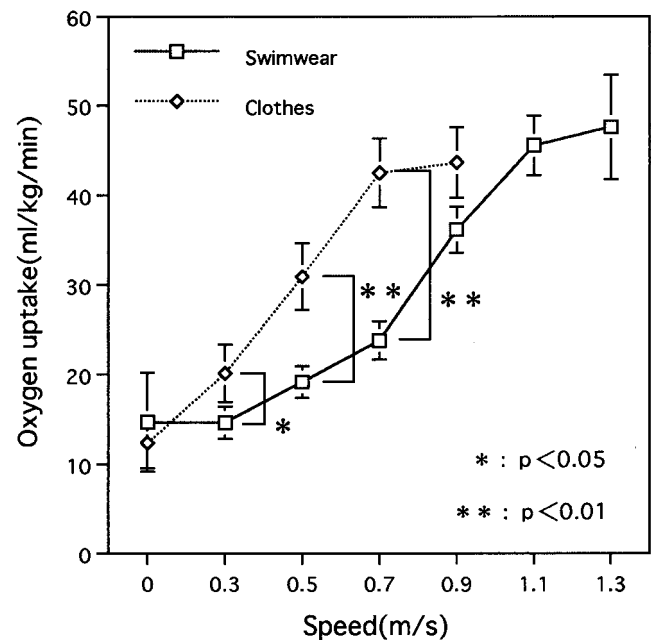


Fig. 2 $\dot{V}O_2$ in relation to speed during the front crawl stroke swimming in swimwear and in clothes.

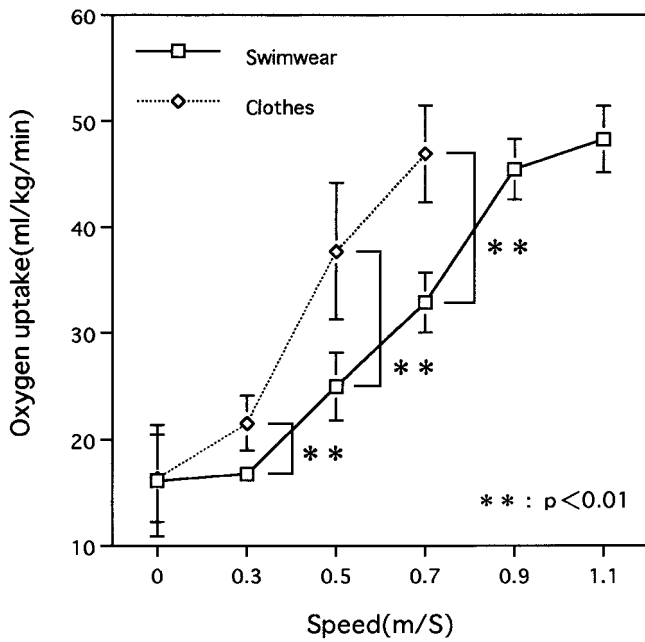


Fig. 3 $\dot{V}O_2$ in relation to speed during the elementary backstroke swimming in swimwear and in clothes.

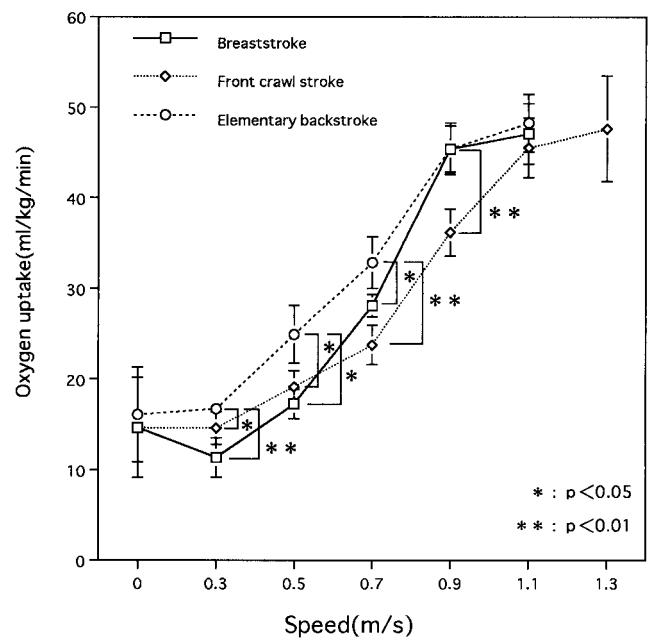


Fig. 4 $\dot{V}O_2$ in relation to speed during the breaststroke, the front crawl stroke and the elementary backstroke swimming in swimwear.

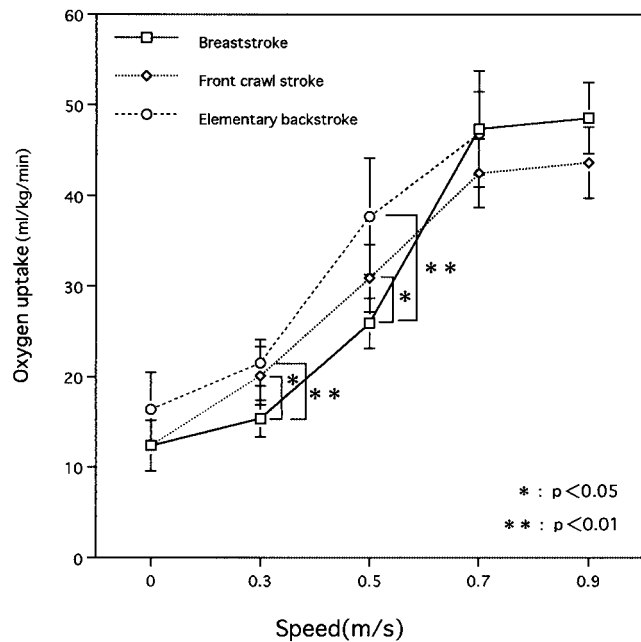


Fig. 5 $\dot{V}O_2$ in relation to speed during the breaststroke, the front crawl stroke and the elementary backstroke swimming in clothes.

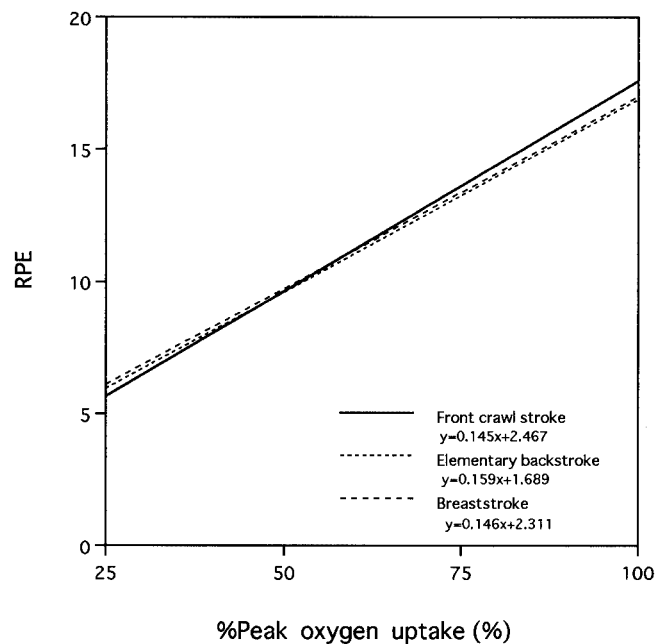


Fig. 6 Linear regression lines between %peak $\dot{V}O_2$ and RPE while swimming in swimwear.

clothed tests. However, at an exercise intensity above 60%peak $\dot{V}O_2$, there was a large difference between the front crawl stroke and two other swimming strokes during the clothed tests.

Discussion

In this study, it was observed that the $\dot{V}O_2$ increased exponentially with the rise in swimming speed in the front

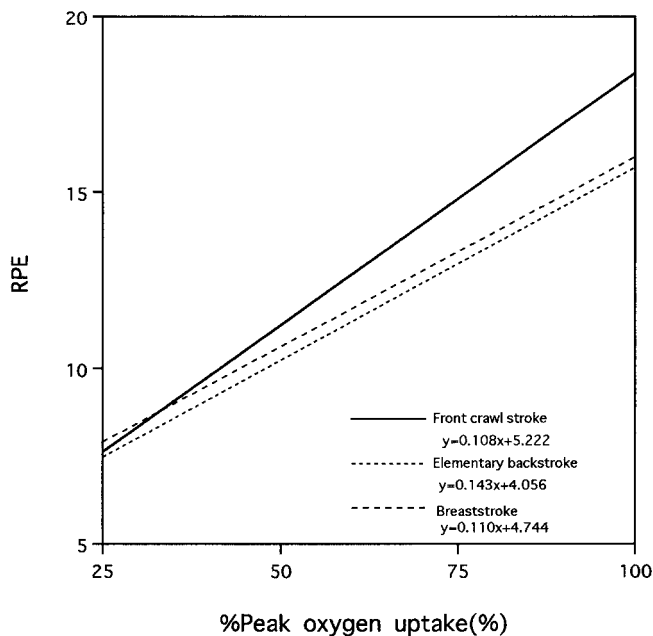


Fig. 7 Linear regression lines between %peak $\dot{V}O_2$ and RPE while swimming in clothes.

crawl stroke and breaststroke in control-sw. The $\dot{V}O_2$ of the subjects during the swimwear tests in the breaststroke was less than that of the subjects during the front crawl stroke at speeds below 0.55 m/s, but the comparison of both strokes was reversed at swimming speeds above 0.55 m/s. Research on $\dot{V}O_2$ in a swimming flume (Holmér, 1974; Sugiyama and Katamoto, 1992) had noted the same results as shown here.

The $\dot{V}O_2$ of the subjects during the elementary backstroke has not been measured. The subjects of this study were not accustomed to the elementary backstroke either because they had not practiced it before the experiment. In this study, $\dot{V}O_2$ in the swimwear tests was higher in the elementary backstroke than in two other swimming strokes. This result may be due to the lowering of swimming efficiency caused by the anomalous motions of the elementary backstroke and the lack of swimming skill in the subjects.

With increases in swimming speed, $\dot{V}O_2$ in the clothed tests was also increased exponentially. $\dot{V}O_2$ in the clothed tests was higher than $\dot{V}O_2$ in the swimwear tests in all swimming strokes and at all swimming speeds. The reason for this is that wet clothes increase resistance under water (Araki et al., 1992). However, the rate of increase in $\dot{V}O_2$ in the clothed tests was comparatively slow at low swimming speeds between 0 and 0.3 m/s, and $\dot{V}O_2$ in the clothed tests was less than 1.4 times as high as that in the swimwear tests in all swimming strokes. These results may be caused by the following factors. The water resistance on a body increases in proportion to the square rate of the

swimmer's swimming speed (Clarys and Jiskoot, 1975). So the water resistance is weaker at slower swimming speeds. The speed of motions in arms and limbs is also low at low swimming speeds. Therefore, a steep drop in swimming efficiency did not occur in clothes-sw.

However, at speeds above 0.3 m/s the rate of increase in $\dot{V}O_2$ in the clothed tests was more rapid than that in the swimwear tests. This allowed differences between the two states to increase in all swimming strokes. Exceptionally, $\dot{V}O_2$ in the swimwear tests and in clothed tests came close in the breaststroke and in the front crawl stroke at a speed of 0.9 m/s. This is because of the levelling off of $\dot{V}O_2$. It could be inferred that differences between the two states increasingly expanded due to increased anaerobic energy at speeds above 0.9 m/s (Andersen, 1960; Holmér, 1974), and consequently, the danger of clothes-sw at high speeds went up as well.

As stated above, Andersen (1960) investigated $\dot{V}O_2$ only in the breaststroke at relatively low speeds, so that the $\dot{V}O_2$ in the swimwear tests at speeds of 0.3 and 0.6 m/s were higher by 36 and 22% respectively than those levels noted in the breaststroke of this study. This is probably due to skill differences between subjects. Five of the seven subjects from his study were unskilled swimmers. In Andersen's study, the $\dot{V}O_2$ of the clothed subjects at speeds of 0.3 and 0.6 m/s were respectively higher by 102 and 22% than those of this study. It seemed that military uniforms and equipment used in his study exerted a larger effect than the clothing used in this study. There were no large differences between the two studies at the speed of 0.6 m/s, but in Andersen's study a considerable elevation of the blood lactate was observed at this speed. Therefore, it can be inferred that there exists a great difference in reality between the two studies because of the mobilization of anaerobic energy.

During the front crawl stroke most of the propulsive force is exerted by the upper body rather than the lower body (Magel, 1970; Mosterd and Jongbloed, 1964). Consequently, it is possible that the weight of wet sleeves burdens the recovery motions of the arms which then causes local muscle fatigue in the shoulders. In this study, the burdened recovery motions may be the reason that peak $\dot{V}O_2$ in the front crawl stroke in the clothed tests was less than those in other strokes. The efficiency decline of the kick motion which is due to the limited range of mobility because the subjects were wearing shoes is also considered a cause of increased $\dot{V}O_2$ during submaximal clothes-sw in the front crawl stroke (Araki et al., 1992).

However, in the breaststroke, the condition of wearing clothes does not remarkably restrict recovery motions of arms because they operate under water. Moreover, it is pointed out that in the breaststroke, running shoes do not put much limit on kick motions, either (Araki et al., 1992). These factors may be the reasons that the $\dot{V}O_2$ of subjects during the breaststroke in the clothed tests at speeds below

0.6 m/s was less than that of the subjects during the front crawl stroke.

The elementary backstroke has been introduced for clothes-sw due to the easiness of breathing and the advantage of recovery motions under water. However, results of this study showed that the $\dot{V}O_2$ of the subjects during the elementary backstroke in the clothed tests was highest among the three swimming strokes. As we already mentioned, this result may be due to the decreased swimming efficiency caused by the anomalous motions of the elementary backstroke and the lack of swimming skill in the subjects.

The most dangerous aspect of clothes-sw is that a swimmer becomes unable to swim because of muscle fatigue in comparison to control-sw. It has been reported that the exercise intensity at anaerobic threshold (AT) was equal to 50-60% $\dot{V}O_2$ max for an untrained person (Ekblom et al., 1968; Karlsson, 1971) and about 70% $\dot{V}O_2$ max for nonendurance athletes (Nagle et al., 1970). Assuming that peak $\dot{V}O_2$ measured in this study compared with $\dot{V}O_2$ max of each subject, the RPE of the subjects at AT could be estimated in clothes-sw to be 12-13 in the breaststroke and the elementary backstroke from Fig. 7. These RPEs can be expressed by a feeling between 'fairly light' and 'somewhat hard'. However, the RPE of subjects performing the front crawl stroke in the clothed tests will be 14. This RPE can be expressed by a feeling between 'somewhat hard' and 'hard'. There was no difference in RPE between the front crawl stroke and other swimming strokes in swimwear, so this difference was a distinctive feature of clothes-sw. In other words, a swimmer might feel that the front crawl stroke was a little 'harder' than other strokes although the exercise intensity was equal. It was made clear that RPE during swimming is formed through the peripheral factors of arms and legs and with the central factors of respiration and circulation (Ueda et al., 1993). As was pointed out earlier, the excessive burden on the shoulders from the recovery motions of arms in the front crawl stroke is considered as the reason for this.

To date, studies that adapted HR as an indicator of exercise intensity (Choi et al., 1994; Choi et al., 1999; Tsubakimoto et al., 1992) have not suggested a proper speed for clothes-sw. From these results, the swimming speeds of the subjects in the clothed tests which were equivalent to 70% $\dot{V}O_2$ max were 0.56 m/s in the breaststroke, 0.47 m/s in the front crawl stroke, and 0.44 m/s in the elementary backstroke. To swim long distances without getting tired while clothes-sw, it is therefore necessary to swim at lower swimming speeds than those given. It should be pointed out that the breaststroke is the most suitable stroke for clothes-sw. However, the energy consumption during swimming is remarkably affected by the swimming proficiency, and unskilled persons consume more energy than skilled swimmers at similar speeds (Andersen, 1960; Holmér, 1974). Consequently, swimming

speeds observed in this study come under the category of skilled swimmers, so that it is predicted that the unskilled person will not have as much speed as a skilled swimmer.

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