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THE EFFECT OF BREATHING ON THE DISTANCE BETWEEN CENTER OF BUOYANCY AND CENTER OF MASS IN COMPETITIVE SWIMMERS

Introduction

Buoyancy is one of the very important parameters determining swimming skill. Some reports indicate that buoyancy affects a swimmer's performance (Cureton, 1933, 1951; Chatard et al., 1990). Swimming is an exercise performed horizontally in water. A human body floating in water is always affected by two kinds of physical influence: buoyancy and gravity. Generally, in a horizontal posture, there is a "gap" between the center of buoyancy (CB) and the center of mass (CM), considering that the CB is around the head and the CM is around the legs (Hay, 1993). The longer the distance between the CB and CM (D), the bigger the torque in the water. This causes the legs to sink and is a factor causing reduced performance. Thus, examining the relationship between the magnitude relation or positional relation of these two forces and the swimmer's performance provides an important index to evaluate swimming skill. Past reports have examined the effect on swimming performance of differences of gender, arm position, and lung volume (Gagnon & Montpetit, 1981; McLean & Hinrichs, 1998, 2000; Zamparo et al., 1996). However, these studies alone cannot provide sufficient explanation for the change of buoyancy affecting human bodies in water. The data generated by these studies reflect samples in extremely restricted environments. For example, some data samples were focused on full expiration "All measurements were made when the subject had achieved the state of full expiration" (Gagnon & Montpetit, 1981). Others examined CB positions with phased lung volumes measured separately "CB was computed from the average of three measurements of five different lung volumes (0, 25, 50, 75, and 100% of vital capacity, VC) with participants in a prone position for each submersion level" (McLean & Hinrichs, 2000). These samples cannot clarify how buoyancy is changed by the continuous cycle of repeated expiration and inhalation (the breathing cycle).

Therefore, this research project will examine the increase and decrease of buoyancy and the migration dynamics of CB position associated with breathing as well as the relationship between the D and performance based on changes in the force exerted in a vertical direction on hands and feet with changes in lung ventilation while a swimmer maintains a horizontal position in the water.

Methods

Sample and Center of Mass Procedures

The participants of this study were 14 male (age = 16.9 ± 0.7 years) and 22 female (age = 16.4 ± 1.1 years) Japanese junior elite competitive swimmers. The body CM

positions were measured by means of a reaction board (Hay, 1993). The subjects were measured on land while maintaining a streamline posture. In this posture, the length from the foot (lateral malleolar) to the hand (center of the fist) is designated as x , and the length from the foot to the CM position of the body is y . Calculations are made using the following equations with weight (W) and force (F) in vertical direction acting on the hand: $y = F \cdot x / W$ (1)

Center of Buoyancy Apparatus

The measurement of the CB point by McLean & Hinrichs (2000) was referred. The frame was installed to secure the subject's body on the poolside and attached tension/compression load cells (LUR-A-200NSA1, Kyowa Electronic Instruments Co.,Ltd.) on hands and feet in a vertical direction to measure the force exerted on the hands and feet in that direction. The sampled signals were amplified by a digital transducer indicator (TD-250T, Takei Scientific Instruments Co.,Ltd.) and recorded by the computer. In all measurements, each subject was instructed to breathe through a snorkel and wear a nose clip to prevent air from leaking out from anywhere other than the mouth. The tips of the snorkels were attached by Pneumotachograph-type sensors (Arco System Inc.) and connected to the dedicated amplifier (FM-200XB, Arco System Inc.) to develop the pressure difference. A hand grip was set on the hand area ($F1$) and a tether was set on the foot area ($F2$). In addition, the hand grip and the tether were set up at depths of 40cm below the water's surface. Furthermore, Four and half kg weight was attached on the hand grip and 2 kg weight was attached on the foot tether so that the subject could stay in water in a stable streamline posture (see Figure 1).

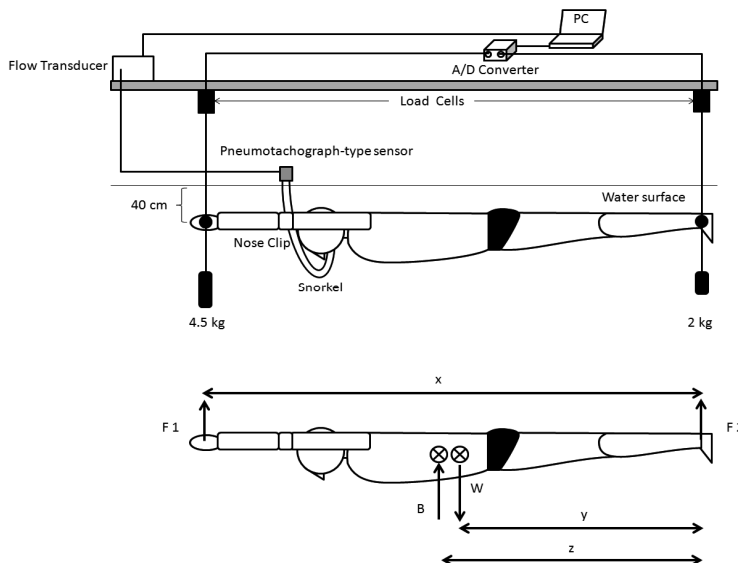


Figure 1. Apparatus used to measure CB and the associated free body diagram

We completely synchronized the data measured by a ventilation flowmeter and a load cell. We implemented calibration with all the experimental apparatus in the set position, offset buoyancy acting on the weights attached on the hand grip and the foot tether, and set the reference value to 0. Calibration was performed in still water.

Center of Buoyancy Measurements and Procedures

The subjects were measured in the CB position while maintaining the streamline posture just as in the CM measurement. The subjects' bodies were completely submerged in water. The load cell was installed on the vertical line passing through the center of the hand grip held by the subject (F1) and on the vertical line passing through the center of the ankles of the subject (F2).

If we assume that the subject stays still in the water, the Buoyancy force (B) can be calculated with the following formula: $B + W + F1 + F2 = 0$

$$B = -W - F1 - F2 \quad (2)$$

The CB position from the foot area (z) can be calculated by using (1) and (2) with the following: $F1x + Bz - Wy = 0$

$$Z = (F1x + Wy) / W \quad (3)$$

Hence, the D in the horizontal posture underwater can be calculated with the following formula: $D = z - y \quad (4)$

The measuring time was on each attempt be 90 seconds and the sampling frequency was 100Hz. All measurements were performed in still water. The time-dependent change of the D was examined as well as the relationship between the distance and the performance by means of quantifying the relationship between the ventilation and forces in vertical direction on the hand and foot areas.

Performance test protocol

A glide-swimming test was used to assess the performance. The calibration was implemented by setting the markers every 2.5m from the starting point of the wall. The subjects started by kicking the wall with both feet to get the longest distance and maintained the streamline posture as long as their breath lasted. The subjects were shot with two underwater video cameras. The real coordinates of the vertex points were calculated by the two-dimensional DLT method. The total moving distance, the average velocity of each 2.5m, and the velocity decrement rate (VDR) of the test also were calculated.

Results

The characteristics of the subject and results of this experiment were shown Table1.

Table 1. Result of the body characteristics, the center of buoyancy (CM) and of mass (CM), the distance between the CB and CM (D), the lung volume and glide-swimming test

Variable	Males (N=14)	Females (N=22)	p
Body length (cm)	212.1 ± 5.9	200.1 ± 7.1	<0.01
Body weight (kg)	61.9 ± 4.5	51.0 ± 4.0	<0.01
CM (cm)	102.0 ± 2.3	96.8 ± 2.3	<0.01
D at neutral buoyancy (cm)	1.93 ± 0.21	1.36 ± 0.17	<0.01
D at full inhalation (cm)	2.28 ± 0.44	2.01 ± 0.35	=0.058
Lung volume at neutral buoyancy (ml)	2366.38 ± 831.67	1327.69 ± 483.71	<0.01
Lung volume at full inhalation (ml)	3185.26 ± 906.55	2604.98 ± 570.01	=0.052
Distance of glide-swimming (m)	13.3 ± 1.2	14.0 ± 1.6	n.s.

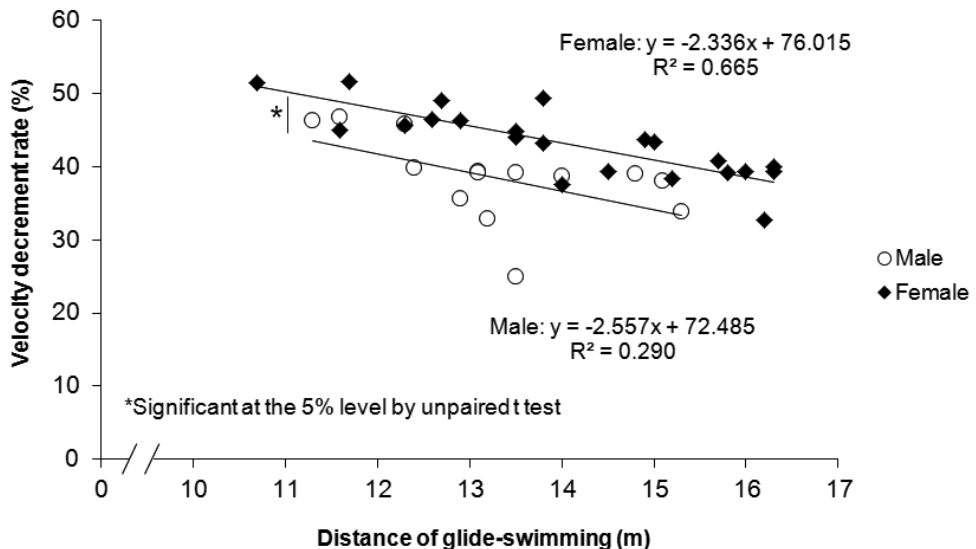


Figure 2. Relationship between velocity decrement (from section B to section C) and distance of glide-swimming

As regards the average velocity at the glide-swimming test in the three sections of 2.5m to 5m (section A), 5m to 7.5m (section B) and 7.5m to 10m (section C), the velocity of male swimmers was significantly faster than that of female swimmers ($p < .01$). The VDR from section B to section C was smaller for women than men ($p < .05$) (see Figure 2). Furthermore, A negative correlation was indicated ([male: $R = -0.539$, $p < .05$], [female: $R = -0.816$, $p < .001$]) between the distance of the glide-swimming test and the VDR from section B to section C.

Discussion

The preceding study by McLean and Hinrichs (1998) reported that the CB/CM distance is shorter for females than males. McLean and Hinrichs indicated that this is caused by a difference in body-fat percentage and the distribution difference of fat tissue between men and women. The authors stated that the volumetric distribution difference of parts of the body submerged in water may affect the CB positions of males and females. On the other hand, as Delavier (2003) stated, because “the lumbar curve is greater in women and the pelvis is tilted,” we infer that the female-specific skeletal structure may contribute to lifting lower limbs and may be involved in maintaining the horizontal posture. The result obtained by this study also revealed that the D is significantly shorter for females than males, which supported the result of McLean and Hinrichs.

A statistically significant difference was observed on the lung volume at a neutral buoyancy between male and female. Furthermore, the lung volume at full inhalation of male was observed larger tendency than one of female. When we compare male and female using the increasing ratio of the lung volume at a neutral buoyancy to the lung volume at full inhalation, the ratio is 34.6% and 96.2% in male and female, respectively. The influence exerted by a difference in thoracic flexibility is considered one of the factors that made the lung ventilation change rate in water bigger for female swimmers than for male swimmers. Generally, it is said that the female skeletal structure is smaller and moves more smoothly and finely than the male one (Delavier, 2003). The female thoracic cage is generally more rounded and not as big as the male's. Proportionately, the skeletal width of the shoulders is the same as in the male, but the larger muscular development of the latter makes it seem wider. It is considered that the male muscle group around the thoracic cage functions strongly to maintain posture. Because the development of female muscles around the thoracic cage is less than in a male, extra pressure is not put on the thoracic cage. Thus it is inferred that the female thoracic cage has high mobility.

In other words, these results indicate that female swimmers can ventilate more air volume while maintaining the buoyancy than male swimmers in the horizontal posture. Thus the results suggest that not only the difference of fat tissue in the body, which has been indicated, but also the difference in lung ventilation ability may influence the ability to maintain a horizontal posture in water. These results indicate that female swimmers have a potential to use buoyancy more effectively and could maintain a better horizontal streamline position.

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THE EFFECT OF BREATHING ON THE DISTANCE BETWEEN CENTER OF BUOYANCY AND CENTER OF MASS IN COMPETITIVE SWIMMERS

Introduction: Buoyancy is an important parameter in swimming. Previous studies suggested that gender, arm position, and lung volume influence natural buoyancy characteristics (Gagnon & Montpetit, 1981; McLean & Hinrichs, 2000). However, these data have not fully described the changes in natural buoyancy. For example, most previous studies measured center-of-buoyancy when participants held their breath. The purpose of this study was to examine the effect of breathing on the distance (d) between Center-of-buoyancy (CB) and Center-of-mass (CM), and its relation to glide-swimming performance. Method: The participants of this study were 14 male and 22 female Japanese Junior elite competitive swimmers. A reaction board (Hay, 1993) was used to locate CM for each participant while they lay in prone position with both arms held above the head (a streamline posture). The participant submerged and took the same posture for

the measurement of CB. In both measurements, the changes of CM and CB were measured in relation to the changes of the lung volume which was measured by a flow instrument. The distance covered by glide-swimming was measured with the participant pushing off from the wall. Results: The result of d showed significant differences ($p < .05$) between the male (1.93 ± 0.21 cm) and the female swimmers (1.36 ± 0.17 cm) during hovering position (a neutral buoyancy). However there was no significant difference during full inspiration (male: 2.28 ± 0.44 cm, female: 2.01 ± 0.35 cm). The distance of the glide-swimming was not significantly different between the male and the female swimmers. Discussion: The results of this study showed that the change of CB with breathing was larger for the female swimmers than for the male swimmers. Also, the distance between CB and CM became smaller in the female swimmer during neutral buoyancy. These results indicated that the female swimmers have a potential to use buoyancy more effectively and could maintain a better horizontal streamline position. References: Gagnon M, Montpetit R (1981). *Journal of Biomechanics*, 14, 235-41. McLean SP, Hinrichs RN (2000). *Research Quarterly for Exercise and Sport*, 71(2), 182-9.

“Dan”, 3. april 2014.

МЕЂУНАРОДНИ 10. КОНГРЕС И 11. КОНФЕРЕНЦИЈА ЦРНОГОРСКЕ
СПОРТСКЕ АКАДЕМИЈЕ ПОЧИЊУ СЈУТРА У ПОДГОРИЦИ

Из 18 држава 138 научника

Свечано отварање 11. међународне научне конференције о трансформационим процесима у спорту „Спортска достигнућа“ и десетог Конгреса Црногорске спортске академије обавиће се у петак у 16 часова у згради Ректората Универзитета Црне Горе, док рад по сесијама почиње истог дана у 10 часова и наставља се

лагати своја научна достигнућа. Иначе, међу гостима који ће се обратити учесницима су проф. др Предраг Мирановић, ректор УЦГ и министри из Владе РЦГ – просвјете и спорта Славољуб Стијеповић и науке Сања Влаховић.

– На овогодишњој конференцији регистровано је 63 научника који ће излагати

ра аутора веома шаролика, тј. аутори су са свих страна свијета, рекао је проф. др Душко Бјелица, председник припремачког одбора 10. Конгреса ЦСА. – Према програму рада, одмах након свечаног отварања предвиђена су пленарна предавања проф. др Зорана Милошевића са Факултета спорта и



Отварање у петак у 16 часова

наредног дана у истом термину. Поред двије оралне паралелне сесије, на програму су, по први пут и двије паралелне постер сесије гдје ће аутори путем постер презентација из-

своје радове, док је укупан број аутора и коаутора на радovima 138. Интересантно је истаћи да овогодишње скунове краси чињеница да је национална структу-

физичког васпитања и доп. др Седжика Акишара са Департамана за спорт Невшехир Хаџи Бекташ Вели Универзитета, рекао је проф. Бјелица. Т.Б.