MAGNITUDE OF MAXIMUM SHOULDER AND HIP ROLL ANGLES IN BACK CRAWL AT DIFFERENT SWIMMING SPEEDS

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The purpose of this study was to identify the characteristics of maximum shoulder and hip roll angles in back crawl at different swimming speeds. Ten male elite swimmers performed back crawl at four different swimming speeds. The swimming trials were filmed by a total of six digital video cameras and three-dimensional coordinates of swimmer's anatomical landmarks were calculated using the three-dimensional direct linear transform. The data were input to a MATLAB programme to calculate linear and angular kinematics. Among the four speed trials, maximum shoulder and hip roll angles were unchanged, and maximum shoulder roll angle was significantly larger than maximum hip roll angle in all trials. In conclusion, the swimming speed does not affect swimmer's shoulder and hip roll angles in back crawl swimming.

KEYWORDS: Swimming, Back crawl, Backstroke, Body roll, Shoulder roll, Hip roll

INTRODUCTION: Body roll is the angular motion of the trunk about the long axis of the body, which is observed in front crawl (FC) and back crawl (BC) in swimming. Body roll consists of shoulder roll (SR) and hip roll (HR), which indicate the roll of the upper and lower trunk respectively (Psycharakis & Sanders, 2010). Payton et al. (1997) investigated the effect of body roll on hand kinematics, and concluded that body roll affects displacement and speed of the hand in the plane perpendicular to the swimming direction, and thus it might affect lift propulsive forces produced by the hand. Lecrivain et al. (2010) conducted a computational fluid dynamic study to investigate the effect of body roll on propulsive forces produced by the upper arm and reported that the increase in body roll increases the propulsion by the upper arm. Clarys and Jiskoot (1975) investigated passive drag in the prone and side (45 degrees roll angle) of the swimmer, and showed significantly less passive drag in the side position than in the prone position. Castro et al. (2003) indicated that one of the important roles of body roll is to prevent undesirable lateral movements of the body during swimming, which would create resistive forces. Furthermore, the effect of the body roll on the rhythm and range of motion of the lower limbs about the longitudinal axis was reported by Sanders & Psycharakis (2009). Researchers have also found that body roll angle in FC decreases as the swimming speed increases (Castro et al., 2003; McCabe et al., 2015). These findings suggest that body roll affects FC performance.
However, few attempts have been made to investigate the relationship between body roll angle and swimming speed in BC. Considering that the above-mentioned effects in FC may also be possible for BC performance, it is important to investigate how body roll angle changes in relation to swimming speed in BC. Therefore, the purpose of this study was to establish the relationships between body roll angle and swimming speed in BC.

METHODS: Ten male elite swimmers were recruited for this study (mean ± standard deviation: age= 17.1 ± 0.99 years; height= 179.1 ± 5.47 cm; weight= 69.9 ± 6.49 kg; 100m BC best record= 60.5 ± 1.29 seconds). More than 24 hours prior to the testing, each swimmer's onset of blood lactate accumulation speed (V_{OBLA}) was identified using a 7×200m BC incremental test proposed by Fernandes et al. (2011) to establish each swimmer's individual testing speeds. Prior to the speed trials, a calibration frame with dimensions of 6m length, 2.5m height, and 2m width was set in the centre of the pool to optimise the distance for all cameras (two above the water and four under water cameras, Sony, HDR-CX160E, Tokyo, Japan). The volume of the calibration space (30m^3) was large enough to cover one stroke cycle of the swimmers. A total of 19 anatomical landmarks of the swimmers were marked using black oil and wax based cream to facilitate identification of these points in the subsequent digitising process. The participants were also photographed in a calibrated space on the poolside from frontal and sagittal views to apply the elliptical zone method to obtain personalised body segment data using a computer programme (eZone) developed by Deffeyes and Sanders (2005). Followed by a 10 minute warm up session, swimmers were instructed to do a 4×50m BC test at 107%, 115%, 122%, and 130% of V_{OBLA} with randomised order because these speeds represent approximate speeds of 400m, 200m, 100m, and 50m race speeds respectively (Dekerle et al., 1999; Wakayoshi et al., 1993). Swimmers' speeds were controlled by a visual light pacer (Pacer2, GBK-Electronics, Aveiro, Portugal) to minimise the error between the actual swimming speed of the participants and the instructed testing speeds.

After the testing session, the video files of the six cameras were transferred into a computer, and the anatomical landmarks of the swimmers during one stroke cycle, defined as the period from entry of one hand to the subsequent entry of the same hand, and reference points on the calibration frame in the video files were manually digitised with digitising frequency of 25-Hz using Ariel Performance Analysis System software (Ariel Dynamics, Inc, CA). The landmarks in the photographs for the eZone were also manually digitised to apply the elliptical zone method to quantify the segment mass and centre of mass (COM) positions. Using the personalised body segment data obtained by eZone and the 3D coordinate data during the stroke cycle obtained by APAS, the location of COM of the body during the stroke cycle was determined by summing the moments of the segment COM mass about the x, y, and z reference axes. The mean COM speed (V_{COM}) was determined by the mean magnitude of COM velocity of the body during the stroke cycle which was obtained by differentiating the COM displacement with respect to time. To investigate body roll angle in BC, SR and HR angles were measured respectively since it was suggested that the magnitudes of SR and HR are significantly different and SR and HR are independent (Psycharakis & Sanders, 2010). SR and HR angles were calculated as the angle between the horizontal and the unit vector of the line joining the shoulder/hip joints respectively projected onto the y-z plane (the vertical plane perpendicular to the swimming direction).

A one way repeated measures ANOVA and pairwise Bonferroni post hoc tests were used to assess the significance of the differences of maximum shoulder roll angle (SR_{max}) and maximum hip roll angle (HR_{max}) between the testing speed conditions. The correlation between the instructed testing speed, V_{COM}, SR_{max}, and HR_{max} of the swimmers were calculated by Pearson's product-moment correlation coefficient respectively. Differences between SR_{max} and HR_{max} at each trial were also assessed by a repeated measures student's t-test. All statistical tests were conducted using IBM SPSS statistics 19 (IBM Corporation, Somers, NY, USA). Statistical significance was set at $p < 0.05$.

RESULTS: Table 1 shows the mean value and standard deviation of the measured variables and the significance of the main effect of the testing speed on the variables. There was a significant main effect of the testing speed on V_{COM} of the swimmers ($p<0.01$). There were no significant main effects of the testing speed on SR_{max} and HR_{max}.

Table 1: Relationships between the testing speed and V_{COM}, SR_{max} and HR_{max}. (Mean ± SD)

	107%-V_{OBLA}	115%-V_{OBLA}	122%-V_{OBLA}	130%-V_{OBLA}	Main effect of the testing speed
V_{COM}($m \cdot s^{-1}$)	1.25±0.10	1.34±0.09	1.41±0.10	1.54±0.06	p<0.01
SR_{max} (degrees)	49.99±9.14	51.47±7.35	51.05±8.10	49.73±5.73	p=0.62
HR_{max} (degrees)	42.21±10.25	43.01±8.23	42.97±8.08	39.83±7.25	p=0.27

Figure 1 shows differences in SR_{max} and HR_{max} between each testing speed (results from post-hoc tests), and differences between SR_{max} and HR_{max} at each trial (results from student's t-tests). There were no significant differences in SR_{max} and HR_{max} between each trial, except HR_{max} between 115%- V_{OBLA} trial and 130%-V_{OBLA} trial. SR_{max} is significantly larger than HR_{max} at all testing speeds.

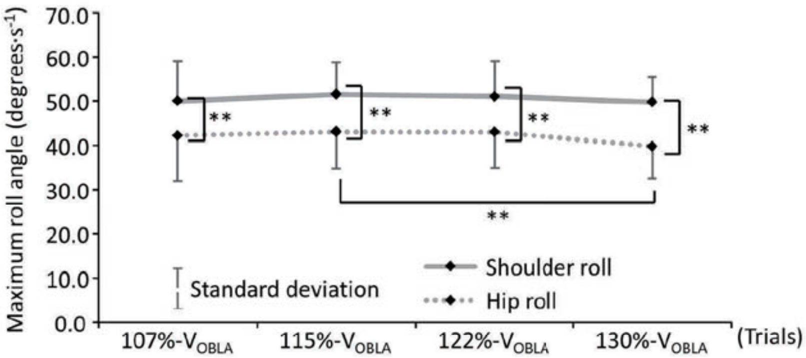

Figure 1: Differences in SR_{max} and HR_{max} between each trial, and differences between SR_{max} and HR_{max} at each trial. **p<0.01

Table 2 shows correlations between the testing speed, V_{COM}, SR_{max} and HR_{max} respectively. There was a significant correlation between the testing speed and V_{COM} (r=0.86, p<0.01), and SR_{max} and HR_{max} (r=0.87, p<0.01), however, there were no significant correlations between V_{COM} and SR_{max}, and between V_{COM} and HR_{max}.

Table 2: Correlations between the testing speed, V_{COM}, SR_{max} and HR_{max}. **p<0.01

	Testing speed	V_{COM}	SR_{max}	HR_{max}
Testing speed	-	r=0.860**	r=0.016	r=-0.133
V_{COM}	r=0.860**	-	r=-0.002	r=-0.072
SR_{max}	r=0.016	r=-0.002	-	r=0.869**
HR_{max}	r=-0.133	r=-0.072	r=0.869	-

DISCUSSION: In this study, there was a strong positive correlation between instructed testing speed and V_{COM}. These results indicate that swimmers successfully conducted each trial at different swimming speeds in the calibrated space according to the instruction.
Although there was a significant difference in HR_{max} between 115%-V_{OBLA} and 130%-V_{OBLA} trials, there were no significant main effects of the testing speed on SR_{max} and HR_{max}, and there were no significant correlations between V_{COM} and SR_{max}, and between V_{COM} and HR_{max}. These results indicate that changes in body roll angle with swimming speed in BC were small. This finding differs from the finding of studies in FC where body roll has been reported to decrease with increase of the speed (Castro et al., 2003; McCabe et al., 2015). This difference between FC and BC is probably due to the difference of the stroking pattern between FC and BC. In FC, swimmers place their upper limbs under the body during the underwater stroke, whereas swimmers place their upper limbs at the side of the body during the underwater stroke in BC which would create large lateral motion of the body. To prevent the potential large lateral motion of the body, swimmers should maintain their body roll angle in BC since one of the important roles of the swimmer's body roll is to prevent undesirable lateral movements during swimming (Castro et al., 2003). On the other hand, to decrease body roll angle in FC might have an important effect on FC performance. Takagi et al. (2015) suggested that swimmers might change their FC stroke patterns from S-shape pattern to I-shape pattern to increase their stroke frequency. Considering that body roll contributes to lateral hand motion (Payton et al., 1997), it is possible that the swimmer decreases the magnitude of their body roll to change their stroke pattern to produce higher stroke frequency in FC.

The larger SR_{max} than HR_{max} in BC is in accordance with body roll characteristics of FC which have been reported in previous studies (Psycharakis & McCabe, 2011). The larger SR_{max} than HR_{max} in BC is reasonable considering that the kicking action restricts HR but has a minor effect on SR (Sanders & Psycharakis, 2009). Although the reported effect of the kicking on the body roll was based on FC data, considering that both FC and BC have similar alternating stroke pattern and six beat kicking patterns in a stroke cycle, it is reasonable to assume that the leg kicking also affects HR motion more than SR motion in BC. Another possible explanation of the larger SR_{max} than HR_{max} in BC is that the additional force might affect SR motion since swimmer's SR is assisted by the second down-sweep motion of the hand in BC (Counsilman, 1968).

In this study, only SR_{max} and HR_{max} at different swimming speeds in BC were investigated, and differences in patterns between SR and HR or the rolling rhythm of shoulder, hip, and other parts of the body such as knees and ankles are unclear. Thus, it will be of interest to investigate a more detailed body roll pattern in BC in future studies.

CONCLUSION: In BC, SR_{max} and HR_{max} during a stroke cycle do not change with the change of the swimming speed, and SR_{max} is larger than HR_{max}.

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