Comparison of advanced and intermediate 200-m backstroke swimmers' dominant and non-dominant shoulder entry angles across various swimming speeds

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Abstract
During backstroke, an optimum shoulder entry angle of 180° has been anecdotally suggested; however, this has yet to be investigated biomechanically. The aim of this study was to quantify shoulder entry angles for advanced and intermediate backstroke swimmers. Six advanced (season’s best < 150 s) and six intermediate (season’s best > 160 s) 200-m backstroke swimmers had markers applied to the medial humeral epicondyles and glenoid cavities. Following a familiarization period, participants completed backstroke swimming trials (90 s each) in a swimming flume at 50%, 60%, 70%, and 80% of their season’s best 200-m velocity. A camera positioned above the flume recorded frontal plane motion, which was digitized and analysed in Simi Motion Systems. The mean peak angle between the upper arm and the line of progression was established in ten strokes for each participant. The results showed backstroke shoulder entry angles for advanced swimmers (170°) were significantly closer to the suggested optimum 180° compared with those of intermediate swimmers (161°). The non-dominant arm displayed values closer to the optimum (171°), while swimming speed had no effect on backstroke shoulder entry angle. In conclusion, backstroke shoulder entry angle may help discriminate between advanced and intermediate backstroke swimmers and may be influenced by laterality dominance, being independent of swimming speed.

Keywords: Swimming, backstroke, shoulder angle

Introduction
Backstroke technique produces a constant propulsive action due to alternating actions of the arms and legs, while the body maintains a streamlined position (Whitten & Lafontaine, 2001). The majority of the power in backstroke is produced by the alternating arm technique, while its horizontal streamlined body position aids efficiency. The legs kick in an alternating action to help balance the action of the arms (Chollet, Seifert, & Carter, 2008). Maglischo (2003) divided the stroke into seven individual phases: entry and stretch, first downward sweep, catch, first upward sweep, second downward sweep, second upward sweep, release and exit and recovery. The arm enters the water when the stroking arm is completing its second downward sweep. Coaching literature suggests that arm entry should be made with the elbow fully extended and with an optimum shoulder entry angle of 180° to the line of progression (Hogarth, 1998). The palm should be facing out so that the hand can enter the water with the little finger first. At water entry, the arm should be streamlined by stretching it forward while completing the second upsweep with the other arm (Masset, Rouard, & Taar, 1999).

Reductions in the shoulder entry angle from the suggested optimum (180°) may increase resistive drag, owing to increases in form and wave drag, reducing performance (Hogarth, 1998). Resistive drag has a major role in the physiological cost of swimming, thus small reductions in resistive drag could result in significant improvements in performance (Mollendorf, Termin, Oppenheim, & Pendergast, 2004). It has been reported that, across all swimming strokes, wave drag accounts for 50–60% of the total passive drag force on elite swimmers (Vennell, Pease, & Wilson, 2005). Form drag is a product of both the volume of the swimmer’s body and the cross-sectional area presented to the oncoming water. It has been suggested that wave drag and form drag can primarily be reduced through improvements in technique (Maglischo, 2003; Pendergast, Mollendorf, Cuvie, & Termin,
In backstroke, deviation from an optimum shoulder entry angle may lead to further resistance in the stroke, caused by lateral deviation (Aron, 2004). Lateral deviation is described as the side-to-side swaying of the hips and legs. In this situation, as the arm enters the water the swimmer can be seen to move in a meandering pattern (Cappaert, Pease, & Troup, 1995). Cappaert et al. (1995) identified that lateral deviation of the body was a major fault in backstroke swimming, leading to an increase in resistive drag. Adjustments in shoulder entry angle can lead to improvements in hand entry position and to reductions in lateral deviation (Gardano & Dabnichki, 2006).

Previous research has identified kinematic differences in stroke mechanics between advanced and intermediate swimmers in all strokes (Cappaert, Pease, & Troup, 1996; Chollet et al., 2008; Leblanc, Seifert, Baudry, & Chollet, 2005; Leblanc, Seifert, & Chollet, 2009; Lerda & Cardelli, 2003; Seifert, Delignieres, Boulesteix, & Chollet, 2007). Although not focusing on shoulder entry angle, Cappaert et al. (1995) reported that the hips and shoulders of elite swimmers rotate more symmetrically and with greater amplitude than those of novice swimmers, resulting in differences in body alignment and greater efficiency of propulsion (Kolmogorov, Rumyanseva, Gordon, & Cappaert, 1997). Cappaert et al. (1996) compared the technique of backstroke Olympic winners with that of swimmers from preliminary heats using videotaped images of the stroke cycle. They identified considerable body roll at the shoulders (49°) and hips (45°) at a similar instant in the stroke for winning swimmers. In contrast, the less successful swimmers were found to display opposing shoulder and hip rotation (45.6° and −39.7°, respectively). Cappaert et al. (1996) proposed that this opposing hip/shoulder rotation increased resistive drag and reduced the use of the trunk muscles in propulsion. The identification of differences in stroke technique between advanced and intermediate swimmers may highlight factors that discriminate superior performance, leading to improvements in coaching and ultimately improvements in performance.

There is limited research comparing dominant and non-dominant arm movements in backstroke swimming (Xin-Feng, Lian-Zel, Wel-Xing, De-Jian, & Xiong, 2007). The only research identified found no difference in shoulder internal and external rotation strength between the dominant and non-dominant arms in swimmers, but called for more research in the area (Ramsi, Swanik, Buz-Swanik, Straub, & Mattacola, 2004). To date, there is also a lack of research into the effect of swimming speed on swimming technique. Shoulder entry angle may change as swimming speed increases due to increases in lateral deviation or over-reaching, which may have a negative effect on performance. This may be particularly evident in less advanced swimmers or in the non-dominant arm.

Previous research has highlighted potential negative consequences of deviations in backstroke shoulder entry angle from the suggested optimum angle of 180°. These consequences include increases in lateral deviations of the body, increases in resistive drag, and ultimately reductions in performance. Therefore, the first aim of this study was to quantify shoulder entry angles for advanced and intermediate 200-m backstroke swimmers. The effect of arm dominance on shoulder entry angle is unknown, although the dominant limb may display a more optimum technique and therefore the second aim of this study was to compare backstroke shoulder entry angles between the dominant and non-dominant arms. Finally, swimming technique may change as swimming speed increases, thus we also wished to compare backstroke shoulder entry angles over various swimming speeds. We hypothesized that:

1. Backstroke shoulder entry angles would be significantly greater in advanced than intermediate swimmers.
2. There would be a significantly greater backstroke shoulder entry angle in the dominant arm compared with the non-dominant arm for advanced and intermediate swimmers.
3. There would be a significant increase in backstroke shoulder entry angles as the speed of swimming increased.

Methods
Following institutional ethics approval, six advanced and six intermediate male backstroke swimmers aged 20.5 ± 1.2 years (mean ± s) volunteered to participate in the study. Participants were classified as advanced if their 200-m season’s best time was less than 150 s, or intermediate if their 200-m season’s best time was more than 160 s. None of the participants had not suffered from any major shoulder injury. Their arm dominance was established based on the hand that they wrote with. Following a comprehensive explanation of the study, participants provided written informed consent to take part in the study.

The study was conducted in a swimming flume (Swimex, America, 600T; 4.2 × 2 m) and all participants had fluorescent markers painted onto their skin, using grease paint. Markers were positioned on the medial epicondyle of the humerus and the glenoid cavity on both sides of the body. Participants completed a 5-min warm-up and familiarization in the swimming flume. To simulate a training
environment, four 90-s trials of continuous backstroke swimming at 50%, 60%, 70%, and 80% of their 200-m season’s best time were then completed. On completion of the four trials, the participants undertook a 3-min warm-down at a self-selected pace and stroke.

A camcorder (Sony TRV900E Digital Camcorder; 50 Hz) was fixed 2.3 m above the water, in the centre of the swimming flume. The camcorder produced a frontal plane field of view of approximately 2 × 2 m. To ensure the participant remained in the field of view, a marker was placed above the flume and the swimmer was instructed to keep their head below the marker. The camcorder aperture was 18 dB with a shutter speed of 1250 frames per second. A two-dimensional calibration object was used to calibrate the anteroposterior and mediolateral axes of the field of view, just above the water line. We minimized the risk of perspective error by recording in the perpendicular plane, with the participant in the centre of the field of view.

Motion capture data were manually digitized and analysed in Simi Motion 2D (version 5.5, Simi Reality Motion Systems GmbH, Germany). We digitized 10 strokes at each exercise intensity (five for the dominant arm and five for the non-dominant arm), beginning at hand entry into the water and ending when the arm was completely submerged in the water (approximately 5 frames). Shoulder entry angles were established between the upper arm segment (medial epicondyle of the humerus to glenoid cavity) and the direction of flow in the swimming flume. Shoulder entry angles were calculated for all the digitized frames, then exported into Excel where the peak shoulder entry angle for each stroke was established and averaged over the five strokes at each exercise intensity, for the dominant and non-dominant arms.

Statistical analysis was undertaken using SPSS 15.0 for Windows. Three main effects were tested statistically: ability (two independent groups: advanced and intermediate swimmers), arm (two independent factors: dominant arm and non-dominant arm), and speed (four repeated measures: 50%, 60%, 70%, and 80% of the participant’s 200-m backstroke season’s best time). The data were checked for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests, which showed that the data were not normally distributed (P < 0.05). Non-parametric comparisons across ability and arm were tested using Mann-Whitney U-tests and comparisons across speed were made using a Friedman test. An alpha of P < 0.05 was established for all statistical tests. Non-parametric relationships between swimming speed and backstroke shoulder entry angle were also assessed using Spearman’s rho correlations, with r-values of 0.1 to 0.29 defining a small relationship, 0.3 to 0.49 a moderate relationship, and 0.5 to 1.0 a large relationship (Cohen, 1988). Absolute typical error measurements (TEMs) in degrees and log-transformed percentage coefficient of variance (%CV) were used to assess the variation in backstroke shoulder entry angle across speeds for both swimming groups and both arms (Hopkins, 2000).

**Results**

Across all swimming speeds the average backstroke shoulder entry angle for advanced swimmers (170 ± 13°) was significantly larger than for intermediate swimmers (161 ± 12°) (P < 0.05). For both groups of swimmers the dominant arm displayed significantly lower backstroke shoulder entry angles (161 ± 14°) compared with the non-dominant arm (171 ± 10°) across all swimming speeds (P < 0.05). The speed of swimming had no significant effect on backstroke shoulder entry angle (x = 2.27[3]), P=0.52).

Figure 1 shows the backstroke shoulder entry angles at each speed for both groups of swimmers and both arms. Statistical analysis revealed various interaction effects for ability and arm, but no interaction effect across swimming speed (Table I). No significant correlations between swimming speed and backstroke shoulder entry angle were identified, either across all data or within each group or arm (r < 0.0007). Following this result, further analysis revealed a low within-participant variance in shoulder entry angle, across swimming speeds (mean TEM of 4.42° and 2.7 %CV).

![Figure 1. Mean values and standard deviations for advanced (n = 6) and intermediate (n = 6) swimmers’ peak shoulder entry angles for the dominant and non-dominant arms, over four swimming speeds. *P < 0.05.](https://example.com/image1.png)
Previous swimming research has examined shoulder anatomy, drag forces, and performance variance between advanced and intermediate swimmers, but this is the first study to compare shoulder entry angles of advanced and intermediate backstroke swimmers. In the present study, advanced backstroke swimmers had a shoulder entry angle (170°) significantly closer to the suggested optimum of 180° than intermediate swimmers (161°), confirming hypothesis 1. The results also showed a significantly greater shoulder entry angle for the non-dominant compared with the dominant arm, rejecting hypothesis 2. Finally, the speed of backstroke swimming had no effect on shoulder entry angle, rejecting hypothesis 3.

The decreased backstroke shoulder entry angles seen in the intermediate swimmers result in the arm entering the water further from the midline of the body, which may increase a swimmer’s cross-sectional area (Payton, Bartlett, Baltzopoulos, & Coombs, 1999). Form drag is affected by the cross-sectional area of the object and the shape of the object has the greatest influence on the form drag contribution to the drag coefficient (McGinnis, 2005), which may affect stroke efficiency at a given velocity. Cappaert et al. (1996) found opposing hip/shoulder rotation in less successful backstroke swimmers, increasing resistive drag. Inefficient utilization of the body roll in intermediate swimmers may affect the positioning of the hand in preparation for the next stroke, which may cause the beginning of the propulsive phase to be lost (Chollet et al., 2008). Hay (1988) stated that this phase of propulsion was effective as the swimmer uses the moving hand in the anteroposterior axis to propel the body forward. The results of this study suggest that these technical aspects may be compromised by intermediate swimmers placing the hand further from the body, thereby reducing the length of the anteroposterior displacement of the hand. It has been suggested that optimizing shoulder entry angle through body roll may reduce swimmers’ cross-sectional area and form drag, while improving propulsion and maximizing stroke efficiency (Chollet et al., 2008). This finding suggests that shoulder entry angle may be a discriminating factor between advanced and intermediate backstroke swimmers.

The present findings indicate a significant difference in shoulder entry angles between the dominant and non-dominant arms for all swimmers. The external rotator muscles of the shoulder play a critical role in providing stability and mobility to the glenohumeral joint during overhead actions such as the backstroke arm entry (Ramsi et al., 2004). Malliou and colleagues (Malliou, Giannakopoulos, Beneka, Gioftsidiou, & Godolias, 2004) reported an increase in eccentric strength in the external rotators of swimmers’ non-dominant arm compared with their dominant arm. Combining these findings may partially explain the greater non-dominant backstroke shoulder entry angle, compared with that of the dominant arm, observed in this study.

Shoulder entry angle during backstroke swimming was unaffected by speed; indeed, this measure showed a low within-participant variance across speeds (2.7 %CV). This finding suggests that backstroke shoulder entry angle is relatively stable in sub-maximum swimming, and instead varies between

<table>
<thead>
<tr>
<th>Swimming speed (% of season’s best time)</th>
<th>Advanced non-dominant arm</th>
<th>Intermediate dominant arm</th>
<th>Intermediate non-dominant arm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Z</td>
<td>P</td>
<td>Z</td>
</tr>
<tr>
<td>50% Advanced dominant arm</td>
<td>-2.74</td>
<td>&lt;0.01</td>
<td>-2.32</td>
</tr>
<tr>
<td>Advanced non-dominant arm</td>
<td></td>
<td></td>
<td>NA</td>
</tr>
<tr>
<td>Intermediate arm</td>
<td></td>
<td></td>
<td>-3.08</td>
</tr>
<tr>
<td>60% Advanced dominant arm</td>
<td>-2.94</td>
<td>&lt;0.01</td>
<td>NS</td>
</tr>
<tr>
<td>Advanced non-dominant arm</td>
<td></td>
<td></td>
<td>NA</td>
</tr>
<tr>
<td>Intermediate arm</td>
<td></td>
<td></td>
<td>-3.13</td>
</tr>
<tr>
<td>70% Advanced dominant arm</td>
<td>-3.00</td>
<td>&lt;0.01</td>
<td>-2.20</td>
</tr>
<tr>
<td>Advanced non-dominant arm</td>
<td></td>
<td></td>
<td>NA</td>
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<tr>
<td>Intermediate arm</td>
<td></td>
<td></td>
<td>-4.14</td>
</tr>
<tr>
<td>80% Advanced dominant arm</td>
<td>-2.16</td>
<td>0.03</td>
<td>-3.06</td>
</tr>
<tr>
<td>Advanced non-dominant arm</td>
<td></td>
<td></td>
<td>NA</td>
</tr>
<tr>
<td>Intermediate arm</td>
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<td></td>
<td>-3.16</td>
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</tbody>
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Note: NA = not applicable, NS = non-significant.
abilities and arms rather than changes in exercise intensity. Further research at maximum or sub-maximum swimming speeds would provide further information on the repeatability of this performance measure.

The present study is the first to investigate the anecdotal optimum backstroke shoulder entry angle of 180°, which is reported in coaching literature. Results from this preliminary study suggest that advanced swimmers display a shoulder entry angle greater than that of intermediate swimmers and closer to the suggested optimum. However, the results of this study should be considered in context. Previous research has shown that swimming flumes, as used in this study, may adjust technical aspects of the stroke; however, it is suggested that this would have been the same for the advanced and intermediate groups in this study. Nevertheless, future research in this area may benefit from pool trials or greater familiarization periods in the swimming flume. We chose to focus on sub-maximum training pace swimming to understand the effect of variations in speed on backstroke shoulder entry angle. Despite the relatively short duration of the trials at each speed and the lack of significance in backstroke shoulder entry angle between speeds, the continuous nature of the protocol may have been affected by fatigue. In addition, due to the non-significant findings, future research may benefit from larger sample sizes and the use of methods other than writing hand to verify upper limb dominance. It would also be interesting to investigate shoulder entry angle at competitive backstroke speeds (e.g. >80% of season’s best) and this could be done with three-dimensional analysis to investigate the relationship between backstroke shoulder entry angle and hip/shoulder rotation (body roll).

In conclusion, this is the first study to kinematically investigate shoulder entry angle during backstroke swimming. We found backstroke shoulder entry angles closer to the suggested optimum of 180° for advanced swimmers than intermediate swimmers during sub-maximum swimming speeds. Previous research would suggest that a shoulder entry angle closer to 180° may reduce lateral deviation of the body during backstroke, reducing resistive drag and potentially improving performance. This result may highlight a discriminating factor of advanced backstroke performance. Interestingly, backstroke shoulder entry angle was greater in the non-dominant than the dominant shoulder. Backstroke sub-maximum swimming speeds did not significantly alter the shoulder entry angle for the dominant or non-dominant arm of the swimmers, suggesting that this measure may be a stable performance indicator.

References

