Kinematic differences between front crawl sprint and distance swimmers at a distance pace

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Abstract

The purpose of the study was to determine whether there are differences in kinematics between sprint and distance front crawl specialists when swimming at a distance pace using a six beat kick. Seven sprint and eight distance male specialists performed one maximum 400 m swim through a 6.75 m³ calibrated space recorded by six gen-locked cameras. The following variables were calculated: average swim velocity, stroke length, stroke frequency, upper limb and foot displacement, elbow angle, the shoulder and hip roll angle, duration of the stroke phases and time corresponding to particular events within the stroke cycle relative to hand entry. Differences between the groups were assessed by an independent t-test and effect size (d) calculations for each variable. The groups only differed significantly with respect to the average swim velocity, with the distance swimmers maintaining a greater velocity throughout the 400 m. However, effect sizes were moderate for elbow angle range during the pull phase (d = 0.78) and the total hip roll magnitude (d = 0.76). There was little evidence to suggest that sprint and distance swimmers using a six beat kick pattern differ in technique when swimming at a distance pace and therefore coaches should not encourage the development of different techniques between these groups.

Keywords: swimming technique, distance pace, sprint specialists, distance specialists

Introduction

Competitive swimmers tend to specialise in either sprint (50–100 m) or distance events (400m+) which is largely determined by their innate or trained physiological and mechanical characteristics (McArdle, Katch, and Katch, 1996; Hohmann, Dierks, Luenhenschloss, Seidel and Wichmann, 1999). Dependent on the specialised event, coaches design training programs to strategically direct the swimmer towards their peak performance by developing physiological aspects appropriate for the event duration (Johnson and Gadboy, 1999; Lydersen, 1999). Additionally there has been considerable speculation that sprint and distance swimmers utilise different stroke technique characteristics in order to achieve maximal performance and as a consequence coaches should develop these techniques accordingly (Costill, Maglischo, and Richardson, 1992; Cappaert, 1999; Ito and Okuno, 2003).

Whilst this seems sensible it may be problematic and unnecessary. Swimmers often engage in aquatic programs at a young age in order to learn how to swim and to develop the correct techniques (Blanksby, Parker, Bradley, and Ong, 1995). After a period of repetitive practice the technique is well established, and then difficult to change once at the ‘autonomous’ stage of learning (Magill, 2001). As a result, there may be a benefit to developing characteristics of technique to suit sprint performance or distance performance early in a swimmers development.

However, this requires early identification of whether a swimmer is more suited to distance or sprint swimming and problems may arise from incorrect assessment of sprint versus distance competitive potential. Also coaches of young swimmers are not sufficiently well informed with regard to identifying distance speciality based on physiological and anthropometric parameters and they may not be sufficiently knowledgeable or experienced to develop the optimal technique for event specialisations.

To address the issue of whether swimmers need to be trained in sprint or distance technique at an early age, it is important to establish (1) What differences exist between the techniques of sprint and distance
swimmers and (2) Whether swimmers adjust appropriately between paces without having had event specific technique development from a young age.

Relative to distance swimmers, it has been reported that sprint swimmers utilise a deeper pulling action of the hand (Cappaert, 1999), a greater extension of the elbow during the underwater stroke cycle (Wilke, 1992; Cappaert, 1999) and a greater knee range of motion during the flutter kick (Cappaert, 1999) in order to maximise propulsion. Cappaert (1999) reported that swim swimmers tend to roll the shoulders approximately 16° less than their distance counterparts and attributed this difference to the shorter stroke cycle durations in sprinting.

It has been suggested that distance swimmers stroke with a reduced vertical displacement of the hand and a smaller internal angle of the elbow, i.e. greater elbow flexion throughout the underwater stroke cycle compared to sprinters in order to reduce the muscular contribution about the shoulder joint and thus minimise energy cost (Vorontsov and Rumyantsev, 2000). Cappaert (1999) proposed that distance swimmers increase the magnitude of shoulder roll as a method of lengthening the stroke and tend to utilise the kicking action primarily for balance rather than a direct source of propulsion compared to sprint swimmers (Watkins and Gordan, 1983; Costill et al., 1992; Vorontsov and Rumyantsev, 2000; Maglischo, 2003). Indeed, when comparing the techniques of sprint and distance swimmers, one factor that has not been addressed is the beat pattern of the kick. It is therefore possible that previous differences observed in technique may have been influenced simply by the kicking frequency i.e. 2 beat, 4 beat or 6 beat rather than differences being associated with the pace.

Despite the findings that sprint and distance swimmers are technically different, the effect of the swim pace was not considered. It is therefore unknown whether sprint and distance swimmers are kinematically different due to their distance specialisation, or whether the differences reported in the existing literature are due to the swim pace. Indeed McCabe, Psycharakis, and Sanders (2011) reported that sprint and distance swimmers do not differ to the extent expressed in the literature, when both groups swim at a sprint pace, suggesting that the swim pace was accountable for the previously observed differences between sprint and distance swimmers. It is unknown whether this is also the case when both groups swim at a distance pace.

McCabe et al. (2011) reported that when swimming at a sprint pace: (1) sprint specialists pull the hand through the pull phase in a shorter period of time compared to distance specialists and (2) distance swimmers obtain maximum shoulder roll earlier in the stroke cycle than sprinters. Because the latter study was the first to directly compare sprint and distance swimmers at a similar pace (sprinting), it is unknown whether these observed differences exist when both groups swim at a distance pace.

Therefore the purpose of this study was to determine whether there are differences in the kinematics of sprint and distance front crawl specialists when swimming at a 400 m pace using a six beat kick.

Methods

Participants

Seven sprint specialists (18.3 ± 2.3 yrs; 75.8 ± 6.4 kgs; 184.4 ± 6.3 cm; 400 m swim time- 4.24.26 mins ± 9.10 sec) and eight distance specialist male swimmers (17.5 ± 2.5 yrs; 72.3 ± 10.5 kgs; 181.8 ± 7.5 cm; 400 m swim time- 4.02.59 mins ± 7.08 sec), who competed at a national and international level, volunteered to participate in this study.

The selection of skilled swimmers was based on an increased likelihood that their stroke characteristics and stroke patterns would be well established and consistent (Pyne, Trewin, and Hopkins, 2004; Nikodelis, Kollias, and Hatzitaki, 2005). Furthermore, the selection of participants required that all swimmers have a preferred kick pattern of a six-beat kick, whether swimming at sprint or distance pace – this facilitated valid comparison between swim techniques without the confounding effect of different kick patterns. All test procedures were approved by the institutional ethics committee and swimmers provided signed written informed consent prior to their participation.

To enable tracking of the swimmers, the following 19 anatomical landmarks were identified: the vertex of the head (using a swim cap), the right and left of the: tip of the 3rd distal phalanx of the finger, wrist axis, elbow axis, shoulder axis, hip axis, knee axis, ankle axis, 5th metatarsophalangeal joint, and the tip of 1st phalanx (big toe). These markers defined a 14 segment body model allowing anthropometric calculations, such as the whole body centre of mass, utilising Defeyes and Sanders (2005) adapted version of Jensen’s (1978) elliptical zone method.

Testing procedure

Each participant was required to swim one 400 m initiated from a push start in a 25 m level deck swimming pool. The instruction given to each swimmer was to maximise their 400 m swim performance. Since previous studies have indicated that the breathing action influences the magnitude of body roll in front crawl swimming (Payton, Bartlett, Baltzopoulous, and Coombs, 1999; Castro, Minghelli,
Floss, and Guimaraes, 2003), all swimmers were required to familiarise themselves with the breath-holding protocol within the calibrated space during their individualised warm-up.

The swimming volume was calibrated using a rectangular prism frame of the following dimensions: 4.5 m length (x), 1.0 m width (y), and 1.5 m height (z) enclosing a calibrated volume of 6.75 m$^3$. The construction of the calibration frame situated it half-below and half-above the water surface with the x axis aligned with the swimming direction. The accuracy and reliability of the three-dimensional coordinate calculation of this frame was established by Psycharakis, Sanders and Mills (2005) who reported small errors which were similar to, or better than, other frames used in three-dimensional studies of movement in large spaces. The calibration frame was recorded by six gen-locked JVC KY32 CCD cameras (four below and two above the water surface) and digitised to yield separate calibration files for the above and below water views using the Ariel Performance Analysis System (APAS) software which incorporates the direct linear transformation (DLT) algorithms of Abdel-Aziz and Karara (1971). The accuracy of the DLT coefficients was enhanced by adjusting the heights of all cameras so that the calibration control points were clearly distinguishable. All six cameras recorded the motion of the swimmer at a sampling frequency of 50 Hz and an electronic shutter speed of 1/120 seconds.

Data processing

One stroke cycle, defined as the period between the instant of hand entry (either right or left) to the instant of hand entry of the same hand, for each 50 m within the 400 m was selected for analysis (total of eight stroke cycles). This meant that the trials digitised were a combination of right and left handed stroke cycles both between and within participants. All swim trials were initiated from a push start at the top end of the 25 m pool and recorded through a calibrated volume that was positioned 5.25 m from the bottom end of the 25 m pool. As a result each selected stroke cycle was captured during the first 25 m per 50 m within the 400 m in order to avoid any possible influence that the swim turn may have on stroke kinematics. APAS was used to manually digitise the nineteen body landmarks separately for the above and below water views from all six camera views and all eight stroke cycles per swimmer. Continuous coordinates for each stroke cycle was obtained by combining the above and below water output files which was then input into a bespoke MATLAB (Mathworks, Inc.) program to calculate all variables. A Fourier transform, regarded as highly appropriate when analysing periodic data such as swimming (Bartlett, 1997), was used to smooth the raw data for each stroke cycle. Six harmonics were retained in the inverse transform corresponding to the highest frequency harmonic retained being between 3.5 to 5 Hz depending on the swimmer’s stroke cycle time.

Data analysis

The average horizontal swimming velocity ($v_{av}$) was calculated by dividing the swimmer’s mean centre of mass horizontal displacement by the time to complete one stroke cycle. Stroke length (SL) was the horizontal displacement of the centre of mass during one stroke cycle. Stroke frequency (SF) was the inverse of the time (seconds) to complete one stroke cycle which was then multiplied by 60 to yield units of strokes per minute.

The vertical motion of the upper limb was represented by the z displacement (m) of the tip of the 3rd distal phalanx of the finger, wrist axis and elbow axis. The z displacement (m) of the 1st phalanx tip (big toe) was representative of the foot’s vertical motion. Both the vertical motion of the upper limb and foot segments were referenced to an external point. The lateral motion of the tip of the 3rd distal phalanx of the finger, wrist axis and elbow axis, with respect to the swimmer’s centre of mass, was calculated as the absolute y displacement (m).

Shoulder and hip roll angles were calculated independently as the angle between the unit vector of the line joining the shoulders and hips respectively, projected onto the yz plane (i.e. the plane perpendicular to the swimming direction, x), and the horizontal (y) axis. Computationally, this is: atan ($S_y$/$S_z$) and atan ($H_y$/$H_z$); where $S_y$ and $S_z$ are the z and y components of the shoulder unit vector and $H_y$ and $H_z$ are the z and y components of the hip unit vector.

The elbow angle was quantified as the arc-cosine of the dot product of the upper arm and lower arm unit vectors. The elbow angle was quantified at five instants within the underwater stroke cycle, namely: 1st back, shoulder x, end back, hand exit, recovery (Figure 1). The elbow angle at hand exit was determined at the moment the finger crossed 0.75 m on the vertical axis (since half of the frame was equally above and below the water). Referring to Figure 1, the elbow angle range during the pull and push phases was calculated as: $X_3-X_2$ and $X_4-X_3$ respectively.

Four separate phases were identified: entry, pull, push and recovery (Chollet, Chalies, and Chatard, 2000; Seifert, Chollet, and Brady, 2004). Each phase, within every stroke cycle, was determined from the swimmer’s horizontal (x) and vertical displacement (y) of the finger and noting the time corresponding to these displacements. Figure 1
illustrates the definition of each discrete phase. Time was expressed as a percentage of the stroke cycle.

**Digitising reliability**

In a previously related study, the authors established that the digitising reliability for each of the variables tested was acceptable due to the reported small errors after digitising one stroke cycle 10 times (McCabe et al., 2011).

**Statistical analysis**

Prior to statistical analysis, the data were assessed for any learning or fatigue effects within the trials. A single factor ANOVA, with the trial number as the factor, was used to evaluate whether any of the stroke cycles’ differed significantly in magnitude relative to each other. This was repeated for each kinematic variable. Within the 400m swim, stroke cycles 1, 7, and 8 were consistently different from those recorded in laps 2, 3, 4, 5 and 6. Therefore, the mean of each variable in the stroke cycles of laps 2, 3, 4, 5 and 6 were used for statistical analysis. To examine the differences between sprint and distance swimmers for each variable, an independent t-test assuming equal variances, was used with a confidence level of $p < 0.05$ accepted as significant. All processed data were analysed using the Statistical Package for Social Sciences (SPSS) version 14.0.

The effect size (d) for each variable was also calculated in order to measure the magnitude of difference between the groups. Interpretation of the effect size data was in accordance to Cohen (1988) whereby effect sizes of greater than 0.2 and less than 0.5 are considered small, greater than 0.5 and less than 0.8 are moderate, and greater than 0.8 are large.

**Results**

**Race parameters**

Distance swimmers were found to have a $0.09 \text{ m s}^{-1}$ greater average swim velocity than sprinters. However, no significant differences were found between the swim groups in relation to the stroke length and stroke frequency variables and the effect sizes ranged from small to moderate (Table I).

**Hand-path**

The vertical or lateral displacements of the upper limb were not significantly different between the
two groups and the effect sizes were small (Table I). At the specified instants throughout the stroke cycle, the magnitude of elbow angle was not significantly different between the groups and the effect sizes were small to moderate (Table I). The elbow angle range during the pull phase approached a large effect size ($d = 0.78$) indicating that sprinters tend to utilise a greater range of motion throughout this phase compared to the distance swimmers.

**Stroke phase durations**

The stroke phase durations and occurrence of the hand exiting the water were not significantly different between the groups (Table I).

**Shoulder and hip roll**

The magnitude of total shoulder and hip roll angle were not significantly different between the sprint and distance swimmers (Figure 2). The effect size between groups was very small for total shoulder roll but approached a large effect size for the total hip roll ($d = 0.77$) indicating that the sprinters tend to display a greater hip range of motion compared to the distance swimmers (Figure 2). The occurrence of both maximum left and right shoulder and hip roll angle was not significantly different between the groups and the effect sizes ranged from small to moderate (Figure 2).
researchers have concluded that the fundamental difference between these groups is the ability of the elite swimmers to reduce their hydrodynamic resistance through a better whole body streamlining position (Toussaint and Beek, 1992; Cappaert, Pease, and Troup, 1996). In fact Cappaert et al. (1996) reported that elite swimmers use less propulsive force compared to the non-elite group, who apply greater propulsive forces to compensate for a poor body position. Thus, one possibility is that the distance swimmers in this study where able to maintain a better hydrodynamic body shape or alignment throughout the 400 m than the sprinters, resulting in a greater average swim velocity. Another possibility is that the sprint swimmers were unable to sustain their propulsive force due to bioenergetic limitations related to their physiology; for example, a greater percentage of fast twitch fibres (Maglischo, 2003). Further research incorporating kinetic analysis together with analysis of physiological energy expenditure is required to shed light on which of these possibilities is dominant. In any case it is recommended that coaches encourage distance swimmers to engage in activities which improve the hydrodynamic characteristics of the swimmers’ body.

The finding that both groups swam at a sprint pace. It is therefore suggested that all swimmers, despite their distance specialisation, display a similar stroke pattern when both groups swim at the same pace. The evidence suggests that swimmers utilise a trajectory of the upper limbs under the water that suits the requirements of the swim event. Consequently, it is recommended that all coaches be aware that at the same pace both groups of specialised swimmers use a similar stroking pattern of the upper limb and should not engage in practices whereby unique techniques are developed and enforced due to the swimmers specialisation per se.

The finding that both sprint and distance specialists stroke with a similar elbow angle magnitude at specified instants throughout the stroke cycle challenges current opinions expressed by Wilke (1992) and Cappaert (1999) but supports those of McCabe et al. (2011). These conflicting findings can be explained due to the fact that both Wilke (1992) and Cappaert (1999) did not take into account the swim pace when examining the swimmers whereas McCabe et al. (2011) compared the groups when both swam at a maximal sprint pace. Based on the results from this study and those of McCabe et al. (2011) it appears that specialised sprint and distance swimmers do not utilise different magnitudes of elbow angle flexion throughout the stroke cycle when both groups swim at the same pace. Consequently it is recommended that coaches and swim teachers do not encourage either group to alter the magnitude of elbow angle throughout the stroke cycle when developing their techniques.
While differences between groups in the range of motion of elbow angle within the pull phase were not significant, the effect sizes ($d = 0.78$) approached the 'large' category as defined by Cohen (1988). The findings from this study suggest that sprint swimmers may utilise a greater range of motion of the elbow angle within the pull phase than the distance swimmers. McCabe et al. (2011) hypothesised that sprint specialists had a trained ability to move their hand through the pull phase faster than the distance specialists when swimming at a sprint pace. It is possible that a greater range of motion of the elbow joint during the pull phase may also be related to the sprinters’ trained ability or musculature. However, since distance swimmers were found to maintain a greater average swim velocity throughout the 400 m compared to the sprint swimmers, it is questionable whether an increased range of motion of the elbow angle within the pull phase is beneficial in terms of the propulsion generated when swimming at a distance pace. Indeed based on the findings of Cappaert et al. (1996), the increased elbow angle range of motion within the pull phase may be utilised by the sprint swimmers to generate more propulsive forces to compensate for a poor body position. Since this study only examined kinematic variables, it is imperative that further research which investigates the kinetic aspects of the swimming stroke is conducted to evaluate the above proposals and substantiate the observation that distinguishes sprint and distance swimmers.

The finding that sprint and distance specialists do not differ with respect to the stroke phase durations when swimming at a distance pace conflicts with McCabe et al. (2011), who reported that sprinters utilise a shorter duration of the pull phase compared to distance swimmers when sprinting. However, the results from this study suggest that both sprint and distance specialist swimmers spend similar durations within each of the stroke phases in order to optimise distance performance. Consequently, coaches should not encourage either group to adjust the temporal aspects of the stroke phases when distance swimming.

It was found that the total magnitude of shoulder and hip roll angle was not different between sprint and distance swimmers when swimming at a distance pace, which is contradictory to the results expressed by Cappaert (1999) but in agreement with McCabe et al. (2011). It is therefore proposed that previous observations that reported distance swimmers roll their shoulders more than sprinters may have been due to the swim pace and not the swimmer's distance specialisation.

The finding that the difference in total magnitude of hip roll between distance and sprint swimmers approached a large effect size ($d = 0.77$) suggests that further investigation should be conducted to determine whether these groups differ in their hip roll patterns when swimming at distance pace. This study indicates that sprint swimmers tend to roll their hips more than the distance swimmers when swimming at a distance pace. It is proposed that the sprinters' greater hip rolling action may also affect their active drag profile by increasing the frontal surface area relative to the distance swimmers. As a result, it is highly possible that the increased total hip roll magnitude of the sprint specialists may have contributed to the lower average swim velocity. Further research is necessary to confirm this observation and the proposed links between the magnitude of hip roll angle and the swimmers' active drag and their impact on swim velocity.

The temporal aspects of the shoulder and hip roll were not found to differ between sprint and distance swimmers, with both groups obtaining maximum shoulder and hip roll, to both sides, at similar times within the stroke cycle. McCabe et al. (2011) reported differences between sprint and distance swimmers in terms of maximal shoulder roll when both groups swam at a sprint pace. However, such differences are not evident in this study and coaches should not attempt to develop different shoulder roll patterns between these groups.

The finding that the amplitude of the kick was not different between groups does not support the view held by Cappaert (1999) but is in agreement with McCabe et al. (2011). It is therefore concluded that when both groups swim at a sprint or distance pace, both specialist swimmers utilised the same kicking amplitude.

**Conclusion**

In the case of most variables, sprint and distance swimmers are generally not sufficiently different in their techniques when swimming at a distance pace to warrant different approaches to technique development. It is most likely that differences between these groups found in previous research were due to the swim pace and not the distance specialisation of the swimmer.

**References**


