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Comparison of starts and turns of national and regional level swimmers by individualized-distance measurements

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Abstract
The aim of this study was to compare the race characteristics of the start and turn segments of national and regional level swimmers. In the study, 100 and 200-m events were analysed during the finals session of the *Open Comunidad de Madrid* (Spain) tournament. The "individualized-distance" method with two-dimensional direct linear transformation algorithm was used to perform race analyses. National level swimmers obtained faster velocities in all race segments and stroke comparisons, although significant inter-level differences in start velocity were only obtained in half (8 out of 16) of the analysed events. Higher level swimmers also travelled for longer start and turn distances but only in the race segments where the gain of speed was high. This was observed in the turn segments, in the backstroke and butterfly strokes and during the 200-m breaststroke event, but not in any of the freestyle events. Time improvements due to the appropriate extension of the underwater subsections appeared to be critical for the end race result and should be carefully evaluated by the "individualized-distance" method.

Keywords: *Kinematics, swimming, performance, two-dimensional DLT*

Introduction

A swim race can be broken down to start, turn, and free swimming phases. The start and turn distances are shorter than the free swimming distance, but they are critical to the final race result as the swimmer is travelling at the fastest velocity in these sections (Tourny-Chollet, Chollet, Hogie, & Papparodopoulos 2002; Welcher, Hinrichs, & George 2008). Start and turns are often further divided for in-depth analysis into subsections such as diving (Balilionis et al., 2012), underwater (Burkett, Mellifont, & Mason 2010), stroking (Vantorre, Seifert, Fernandes, Vilas Boas, & Chollet 2010b), and wall push-off (Araujo et al., 2010). Correlation analyses have demonstrated that the underwater subsection has the greatest influence on the start segment (Cossor & Mason, 2001; Pereira, Ruschel, & Araujo 2006), and swimmers should aim to maximize the velocity off the wall, minimize deceleration with an underwater flutter or dolphin kick, and determine the appropriate timing to commence free swimming in this section (Blanksby, Skender, Elliott, McElroy, & Landers 2004; Hubert, Silveira, Freitas, Pereira, &

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Roesler 2006; Lyttle, Blanksby, Elliott, & Lloyd 2000). Technical modifications to these skills have been found to reduce the start time by 0.10 s (Blanksby, Nicholson, & Elliott 2002) and are repeated in every turn (Burkett et al., 2010). Therefore, coaches should consider that any improvements within the start or turns subsections can have a crucial impact on the overall race success (Bishop, Smith, Smith, & Rigby 2009).

In order to evaluate starting and turning performances, previous studies have used fixed-distance measurements (usually at 7.5 or 15 m from the wall) to define the start and turn distances (Arellano, Brown, Cappaert, & Nelson 1994; Shimadzu, Shibata, & Ohgi 2008). These studies reported that up to 30% and 40% of the total race time can be spent in the start (Vantorre et al., 2010b) and the turn segments (Blanksby, Elliott, McElroy, & Simpson 1998), respectively. Recent research, however, has reported several drawbacks to the fixed-distance procedure. First, the fixed-distance measurements do not relate to a swimmer's movements in the water but to the *Fédération Internationale de Natation* (FINA) rules, which indicate that the head must break the water surface before the 15-m mark in the freestyle, butterfly, and backstroke events (Seifert, Payen, Vantorre, & Chollet 2006). Second, there has not been any clear consensus on the best measures for comparing start and turn variations (Galbraith, Scurr, Hencken, Wood, & Graham-Smith 2008; Tourny-Chollet et al., 2002; Welcher et al., 2008). In addition, the fixed distances could overestimate the start and turn race segments when a swimmer breaks out before the reference mark (Veiga, Cala, Mallo, & Navarro 2013). Finally, the start and turn are fundamentally different skills from the free swimming (Welcher et al., 2008) because the stroking proficiency does not necessarily indicate a similar level of starting (Thompson, Haljand, & MacLaren 2000) or turning (Prins & Patz, 2006) performance.

A new procedure based on individualized-distance measurements has been proposed (Veiga et al., 2013) that could overcome some of the limitations of the fixed-distance procedure and provide a detailed analysis of the race segments (Cossor & Mason, 2001). This "individualized-distance" method defines the start and turn segments up to the instant the head breaks the water surface, and it has been suggested that it will complement the 15 m starting or turning times (Welcher et al., 2008). So far, there have only been a small number of researches using individualized-distance measurements (Chow, Hay, Wilson, & Imel 1984; Miller, Hay, & Wilson 1984; Seifert et al., 2006) and these have been limited to non-proficient swimmers (Blanksby et al., 2004; Pearson, McElroy, Blitvich, Subic, & Blanksby 1998) who are not able to perform consistently (Hopkins, Hawley, & Burke 1999) or to front crawl techniques not performed in a competition situation (Burkett et al., 2010; Takeda, Ichikawa, Takagi, & Tsubakimoto 2009). Some temporal analysis studies have reported that the best swimmers spend a longer time in the underwater phases (Mason & Cossor, 2000; Seifert et al., 2006; Vantorre, Seifert, Fernandes, Vilas Boas, & Chollet 2010a) but, to our knowledge, no study has determined a skill level for starting or turning distance parameters.

The skill level of the swimmers has been related to the competitive turning ability in international and national level swimmers who obtained shorter 15 m turning times in backstroke (Chatard, Girold, Cossor, & Mason 2001), breaststroke (Thompson et al., 2000), butterfly (Tourny-Chollet et al., 2002), and freestyle (Arellano et al., 1994) races. However, there is a lack of existing knowledge concerning possible differences with lower competitive level swimmers. Data on what distinguishes an elite to an average performance level are essential for developing swimmers to higher levels of expertise or for talent identification (Elferink-Gemser, Kannekens, Lyons, Tromp, & Visscher 2010). Therefore, the main objective of this investigation was to compare the race characteristics of the start and turn segments of national versus regional level swimmers. It was hypothesized that national level would obtain longer start and turn distances and that they would outperform regional level swimmers on starting and turning average velocities.

Methods

Participants

In the study, 100 and 200-m events during the finals session of the 2008 *Open Comunidad de Madrid* (Spain) swimming tournament were analysed in a 50 m × 25 m pool. Final times obtaining between 700 and 900 points according to the FINA Point Scoring System were classified as national level performances, whereas those that obtained between 500 and 700 points were classified as regional level. Eighteen performances were excluded for ulterior analysis due to these being out of the score range. In total, 644 performances (337 male and 307 female) in the 100 and 200-m events (four strokes) were analysed (additional details can be found in Table I). Written informed consent was obtained from all the participants before the commencement of the investigation. This study was conducted with the approval of Madrid Technical University's Ethics Committee.

Table I. Participant groups and mean race times ($M \pm SD$) during the 2008 *Open Comunidad de Madrid*.

Event	Competitive level	*n*	End race times (s)	IPS
Men's 100-m breaststroke	National	24	66.06 ± 1.21	756.7 ± 43.1
	Regional	23	69.80 ± 1.08	648.9 ± 30.1
Women's 100-m breaststroke	National	22	74.03 ± 1.66	744.2 ± 52.6
	Regional	24	80.02 ± 1.97	590.3 ± 42.3
Men's 100-m freestyle	National	30	52.35 ± 0.59	785.9 ± 26.7
	Regional	16	53.95 ± 0.78	718.3 ± 29.8
Women's 100-m freestyle	National	26	58.23 ± 0.81	799.0 ± 34.2
	Regional	17	60.45 ± 0.85	713.9 ± 30.1
Men's 100-m backstroke	National	21	59.41 ± 1.13	749.8 ± 44.6
	Regional	23	62.47 ± 1.34	645.2 ± 40.2
Women's 100-m backstroke	National	19	66.14 ± 1.75	760.5 ± 60.5
	Regional	20	70.80 ± 1.94	620.2 ± 48.8
Men's 100-m butterfly	National	18	56.61 ± 1.33	765.5 ± 55.0
	Regional	24	60.11 ± 1.07	638.6 ± 34.0
Women's 100-m butterfly	National	19	63.12 ± 1.40	764.1 ± 51.7
	Regional	23	67.91 ± 1.84	614.3 ± 47.4
Men's 200-m breaststroke	National	15	142.47 ± 2.15	765.0 ± 35.4
	Regional	18	153.49 ± 4.35	613.8 ± 51.3
Women's 200-m breaststroke	National	12	158.39 ± 4.29	752.2 ± 63.0
	Regional	15	169.83 ± 4.49	610.1 ± 47.2
Men's 200-m freestyle	National	19	114.20 ± 1.29	798.8 ± 27.8
	Regional	23	118.94 ± 1.88	707.7 ± 32.6
Women's 200-m freestyle	National	27	125.66 ± 2.20	815.1 ± 42.7
	Regional	16	132.26 ± 1.94	698.6 ± 30.3
Men's 200-m backstroke	National	18	128.31 ± 2.34	753.5 ± 42.2
	Regional	24	135.83 ± 2.85	635.6 ± 39.5
Women's 200-m backstroke	National	13	138.44 ± 3.97	801.3 ± 66.7
	Regional	24	152.66 ± 3.61	596.9 ± 41.9
Men's 200-m butterfly	National	15	126.96 ± 2.23	747.2 ± 39.8
	Regional	26	134.81 ± 4.37	626.8 ± 58.7
Women's 200-m butterfly	National	15	139.53 ± 3.31	749.5 ± 53.8
	Regional	15	150.76 ± 2.90	593.5 ± 32.7

Note: IPS, Fédération Internationale de Natation Point Scoring System.

Data collection

Swimming races were subject to video analysis using the "individualized-distance" method (Veiga et al., 2013). Selected coordinates of the competitors' plane of movement during the race were reconstructed from the screen coordinates by two-dimensional direct linear transformation (2D-DLT)-based algorithms (Abdel-Aziz & Karara, 1971). Sixteen pool-side building marks surrounding the competitive area (eight lanes) were used as control points for calibration purposes. The video footage of the races was captured with two lateral fixed JVC® GY-DV500E video cameras located in the stands (7 m above and 7 m away from the side of the pool), each operating at a frame rate of 25 Hz and with a shutter speed of 1/1,000 s. From their fixed position, the cameras were able to record the first 15 m from the starting and turning wall. The video images were digitized with the software Photo 23D (Technical University of Madrid, Spain; Cala, Veiga, García, & Navarro 2009), and the race's time code was provided by a flashlight connected to the official timing system. The beginning of the turn segment was defined by the last stroke hand entry, as previously described by Chow et al. (1984), while the end of both the start and turn segments was defined by the breakout of the head, which indicated the end of the underwater phase (Burkett et al., 2010; Cossor & Mason, 2001). Free swimming strokes were excluded from both the start and turn segments. Therefore, the free swimming segment was calculated as the total race time minus the start and turn race segments. In addition, no measurements related to the contact times during the turn segment were made due to the difficulty of identifying the instant when the swimmer made first contact with the wall (Chow et al., 1984; Cossor & Mason, 2001). The horizontal distance (m) of the swimmer's head from the beginning to the end of the race segments, time (s), and average velocity (m/s) were calculated. In the 200-m events, where three turn segments occurred throughout the race, distance and velocity were presented as the sum of the three turns.

Previous research (Veiga, Cala, Frutos, & Navarro 2010) determined the validity and reliability of using this methodology for swimming race analysis. The root mean square error when reconstructing the distance between two points was less than 0.05 m, and the reliability tests revealed differences in the measurements that were consistently less than 1%.

Statistical analysis

The data from the 100 and 200-m events were separately analysed using SPSS 15.0 (SPSS Inc., Chicago, IL, USA) and were expressed as *Mean* ± *SD*. Repeated measures MANOVA with the multivariate mixed model (Schutz & Gessaroli, 1987) were used to evaluate the effects of competitive level (national and regional), gender (male and female), and event (e.g. backstroke, breaststroke, freestyle, and butterfly) on the distance and velocity during race segments (start, free swim, and turn). The statistical significance was set at $p < 0.05$ for all statistical analyses, but the alpha level was adjusted by the Bonferroni correction when carrying out multiple comparisons. The meaningfulness of the effects (Knudson, 2009) was determined by the effect size (ES; as partial η^2 values).

Results

The competitive level of the swimmers was found to exert a significant multivariate effect (competitive level × race segment) on the start, swim, and turn segments, both for the 100-m (Wilks' lambda = 0.93, $F_{4,1330} = 12.506$, $p < 0.05$, ES = 0.36) and 200-m (Wilks' lambda = 0.89, $F_{4,1110} = 15.93$, $p < 0.05$, ES = 0.54) events. National level swimmers

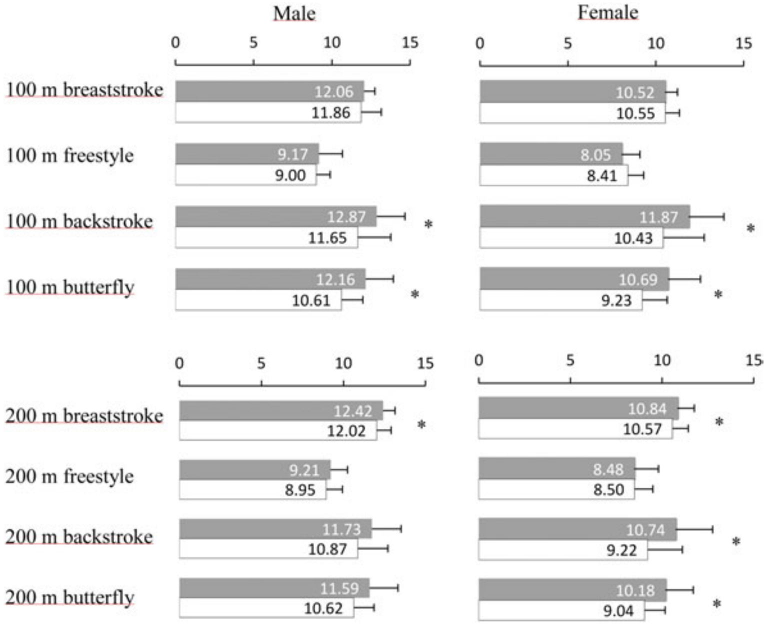

Figure 1. Comparisons of start distance (m) for the national (coloured) and regional (white) competitive levels. *Significant differences between levels ($p < 0.05$).

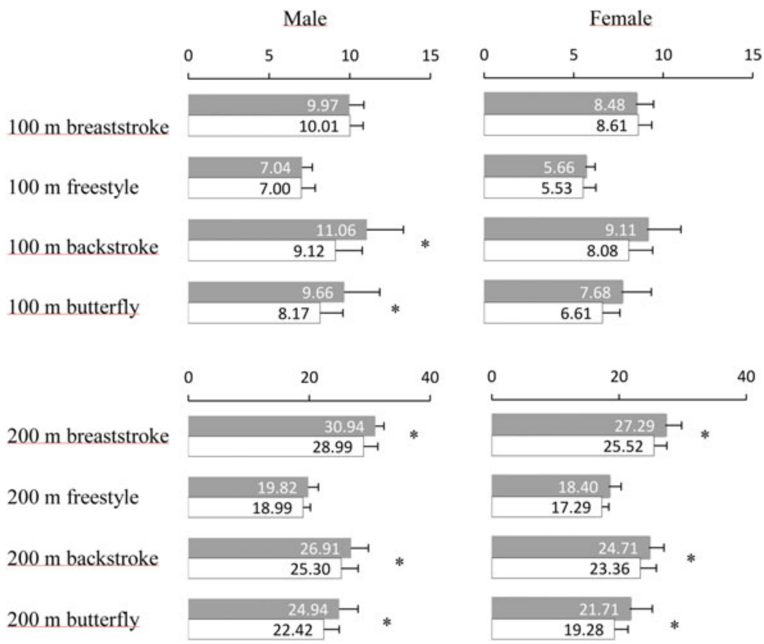

Figure 2. Comparisons of turn distance (m) for the national (coloured) and regional (white) competitive levels. *Significant differences between levels ($p < 0.05$).

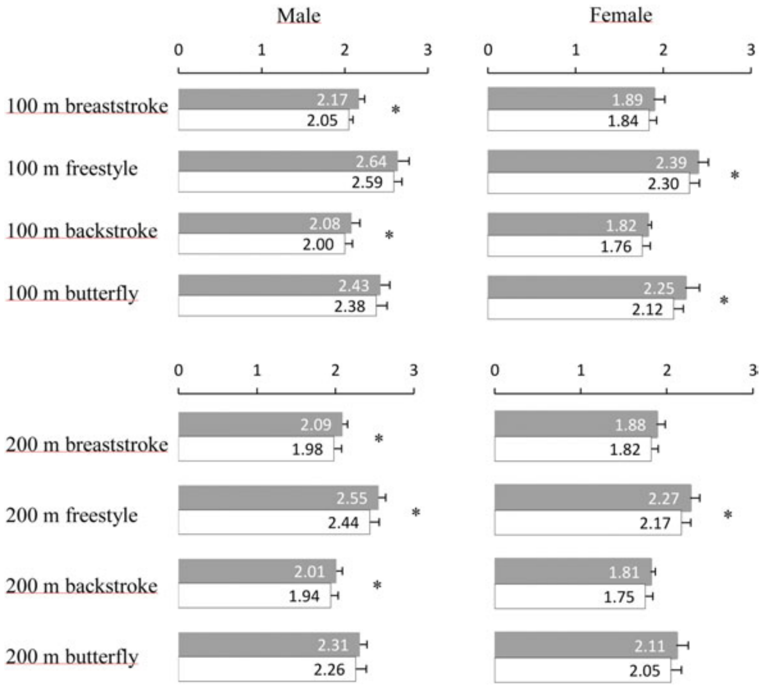

Figure 3. Comparisons of start velocity (m/s) for the national (coloured) and regional (white) competitive levels. *Significant differences between levels ($p < 0.05$).

travelled longer ($p < 0.05$) distances during the butterfly and backstroke start and turns and the 200-m breaststroke turn segments (Figures 1 and 2). However, no statistical differences ($p > 0.05$) were detected between national and regional level swimmers in distances in any of the freestyle race segments. Male swimmers obtained longer distances than female swimmers in all race segment comparisons, regardless of the swimmers' performance level. The contribution of the start and turn distances for both national and regional level swimmers represented less than 24% of the 100 m and less than 22% of the 200 m race distances.

For the average velocity measurements, the national level swimmers had faster velocities than the regional level swimmers throughout all the race segments and stroke comparisons. However, as expressed in Figures 3 and 4, significant differences ($p < 0.05$) were only detected during the start segment in half (8 out of 16) of the analysed events. In the free swimming segment, minimum average velocity occurred in the 200-m breaststroke event (1.25 m/s for male and 1.14 m/s for female regional level swimmers), whereas maximum average velocity was obtained in the 100-m freestyle event for both genders (1.84 m/s for male and 1.67 m/s for female national level swimmers). Differences in average velocity between race segments were obtained for all the events, regardless of the swimmers' performance level or gender. The starting speed was 0.5–0.8 m/s faster than the free swimming speed ($p < 0.05$), and average turning speed was 0.1–0.3 m/s faster than the free swimming speed ($p < 0.05$). Finally, differences in average velocity were also obtained between genders in all race segment comparisons.

Discussion and implications

This study for the first time characterized the individualized starting and turning distances for the different skill levels of swimmers in competition. The first important observation is

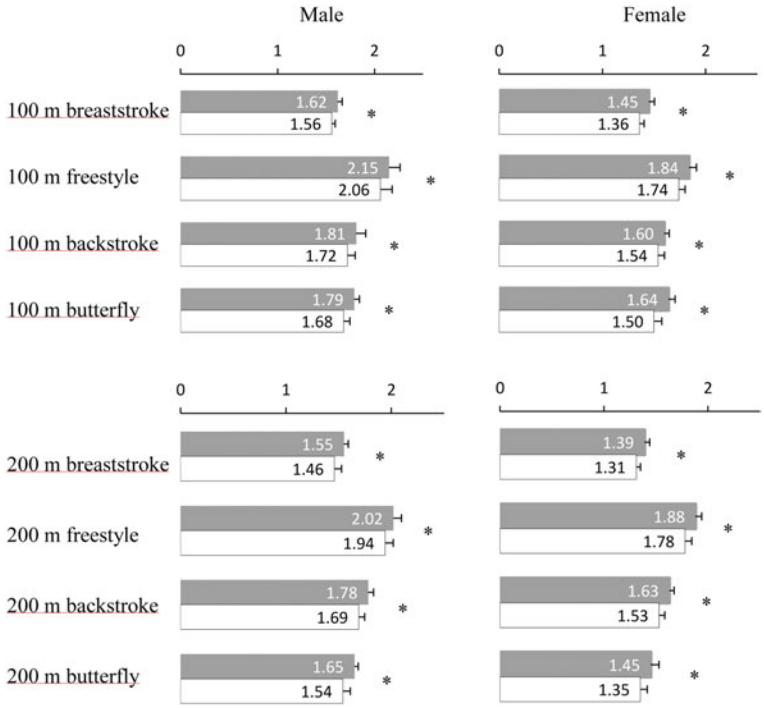

Figure 4. Comparisons of turn velocity (m/s) for the national (coloured) and regional (white) competitive levels. *Significant differences between levels ($p < 0.05$).

that the distance covered by national and regional level swimmers from the beginning of the race to the head breakout was from 2 to 5 m less than when starting times were measured using a fixed distance (15 m). Also, the turn distances from the last stroke before the wall to the head breakout represented a more minor contribution to the race structure than when traditional fixed distances from the wall were used. Totally, the free swimming segment represented at least 76% of the 100 and 200-m race distances.

The second important observation was that, regardless of the swimmers' performance level, the butterfly and backstroke underwater distances were notably longer than the data previously reported in the literature. Hence, swimmers travelled from 3 to 5 m and from 2 to 3 m longer in start and turn distances, respectively, than previously reported international or age group level swimmers (Blanksby et al., 1998; Chow et al., 1984; Miller et al., 1984). After the gliding distance (Vantorre et al., 2010b), national and regional level swimmers covered underwater distances between 6 and 9 m, which correspond to 8–12 dolphin kicks (Zamparo, Vicentini, Scattolini, Rigamonti, & Bonifazi 2012). This represents an important technical evolution in these events and suggests that swimmers obtained both less deceleration and improved average velocity (Clothier, McElroy, Blanksby, & Payne 2000). On the other hand, in the freestyle and breaststroke events starting and turning distances corresponded to past (Chow et al., 1984) and recent research results (Burkett et al., 2010; Pereira et al., 2006; Vantorre et al., 2010b, 2010a). No evolution in the underwater techniques seems to have occurred in these events as the breaststroke rules limit undulatory underwater movements, and no underwater dolphin kick was extensively used by national and regional level freestylers. These observations are of a real practical value, as they could persuade coaches to group backstroke and butterfly specialists into programmes designed to improve their underwater dolphin kicking at the same time as providing them with an objective reference for swimmers performing their stroke and/or event.

Regarding average velocities, both starting and turning speeds were faster than the free swimming speed as previously reported for national (Hubert et al., 2006) and age group level swimmers (Blanksby et al., 2002). This could represent a way to increase average race velocity (Blanksby et al., 1998; Hubert et al., 2006), especially in the slower free swimming strokes (Kjendlie, Haljand, Fjortoft, & Stallman 2006; Tourny-Chollet et al., 2002). If swimmers start underwater kicking after gliding in the speed range 1.9–2.2 m/s (Lyttle et al., 2000), they can extend the underwater section until they slow to the free swimming speed (between 1.2 and 1.8 m/s) and then start stroking. The time improvements, according to these results, could reach 0.1 or 0.2 s when travelling one more metre underwater. This represents the time difference between the first and third place in a sprint event (Breed & McElroy, 2000; Galbraith et al., 2008) and, therefore, it could easily determine the winner among swimmers with similar free swimming performances (Miller et al., 1984; Prins & Patz, 2006).

When the individualized-distance and velocity measurements were compared between genders, the male swimmers showed greater mean values than the female swimmers in all the measurements. Differences between genders (from 1 to 2 m) corresponded to data from the start (Cossor & Mason, 2001; Miller et al., 1984) and turn (Chow et al., 1984) performances and could be explained by the greater muscular power of the legs when pushing off the wall (Krüger, Hohmann, Kirsten, & Wick 2006; Pearson et al., 1998; Vantorre et al., 2010b). Previously, Miller et al. (1984) showed that differences in the heights of males and females did not explain differences in start distance between genders.

When the two performance level groups were compared, national level swimmers obtained higher velocities and longer distances during the start and the turn segments, although inter-event differences were also detected. In the freestyle events, an important finding is that no inter-level distance differences were found in any of the race segments. As the freestyle is the fastest event, there appeared to be no advantage when the underwater subsection of the starts and turns was extended. Another important finding is that longer glide phases in the 100-m breaststroke event could be ineffective in maintaining a higher mean velocity (Seifert et al., 2006). Previous research studies have claimed that longer start and turn breaststroke distances can provide a gain in speed (Blanksby et al., 1998; Seifert et al., 2006) because breaststroke is the slowest stroke. However, these results showed that the faster swimmers travelled for longer distances in the 200-m event only. For the backstroke and butterfly strokes, national level swimmers obtained longer start and turn distances, especially in the turn segment and in the 200-m events. The technical complexity of the underwater undulatory kicking could explain why the best swimmers had the ability to make this phase longer (Gavilan, Arellano, & Sanders 2006; Vantorre et al., 2010a). According to these results, even though swimmers are often encouraged to use the underwater phase as far as the rules permit (Cossor & Mason, 2001), the reality is that the faster swimmers maximized the start and turn distances only when a net gain of average velocity was probable.

Finally, differences between the two skill-level groups were also observed throughout the race. At the beginning of the race, when there was no influence from either previous velocity or fatigue (Thompson et al., 2000; Tourny-Chollet et al., 2002), the start velocity did not appear to be clearly determined by the swimmers' competitive level. This is in line with previous research studies using individualized-distance (Pereira et al., 2006) and fixed-distance (Guimaraes & Hay, 1985; Wakayoshi, Nomura, Takahashi, Mutoh, & Miyashita 1992) measurements. However, in the turn segment, national level swimmers obtained faster velocities than regional level swimmers in all the measurements. Probably, their faster free swimming velocity immediately before initiating the turn could lead to a quicker approach into the wall (Chow et al., 1984) and to higher forces (Tourny-Chollet et al., 2002), which are judged by Newton's third law. Also, the ability of the best swimmers to cope with fatigue and to pace themselves throughout the event (Chollet, Pelayo, Delaplace, Tourny, & Sidney 1997; Kjendlie et al., 2006; Toussaint, Carol, Kranenborg, & Truijens 2006) could explain their better performance in the turns.

The objective data about individualized race segments presented in this study could be a guide to the priority areas for swimming performance enhancement (Burkett et al., 2010), as all the variables measured in the present research can be obtained easily from direct observation or from video footage taken under appropriate conditions (Miller et al., 1984). Coaches and swimmers should prioritize their focus on (1) improving the average underwater velocity and (2) determining the appropriate distance for the underwater section. Start and turn distances should be extended further than 10 m for the butterfly, backstroke, and 200-m breaststroke events, whereas start and turn velocities should be maximized above 2 m/s in the freestyle events. Nevertheless, time improvements demonstrate great inter-individual variability (Vantorre et al., 2010b) and are dependent on the strengths and weaknesses of the individual swimmers. A limitation of this study is that it was not able to provide information about the instantaneous velocity at the point the swimmer transitions from underwater kicking to stroking, which could be a useful indicator of start or turn performance (Welcher et al., 2008).

Conclusion

Higher level swimmers travelled for longer start and turn distances when their underwater velocities were faster than their free swimming velocities. This was observed in the turn segments, in the backstroke and butterfly strokes, and in the 200-m breaststroke event, but not in any of the freestyle events, where no underwater dolphin kick was extensively used by national and regional level swimmers. Time improvements, due to the extension of the underwater subsection, could represent an improvement of 0.1–0.2 s depending on the event and should be carefully evaluated by the "individualized-distance" method.

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