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Effect of functional classification on the swimming race segments during the 2012 London Paralympic Games

Javier Pérez-Tejero[a], Santiago Veiga[a,b], Alberto Almena[a], Archit Navandar[a] and Enrique Navarro[a]

[a]Health and Human Performance Department, Technical University of Madrid, Madrid, Spain; [b]Madrid Swimming Federation, Madrid, Spain

ABSTRACT
The aims of the present research were (1) to characterise the individualised race segments configuration (start, turn and free swimming) of Paralympic swimmers and (2) to examine the influence of the swimmers' functional classification on their race segments configuration. Finalists (248 men and 264 women) in the 100 m swimming events of the 2012 London Paralympic Games were distributed in five different subgroups based on their functional class designation and race performances were video-analysed with 2D-DLT algorithms. The start and turn distances of Paralympic swimmers in the 100 m events did not coincide with the traditional 10–15 m segments and they depended on the swimmer's functional group ($\eta^2 = 0.48$), as longer start and turn distances were observed according to the lower degree of impairment of swimmers. However, no differences were observed in the start and turn distances of the least physically impaired, the visually and the intellectually impaired swimmers (S8–S14), regardless of the stroke and gender. These results indicate that, in terms of the race segments configuration, there is no evidence to support the classification of S8–S14 swimmers in different functional classes.

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Disability; competition; kinematics; methodology and performance analysis

1. Introduction

Functional classification is a fundamental concept in Paralympic sport. Its main purpose is to evaluate the influence of the athlete's impairment on sports performance and to ensure that the athlete participates on equal terms with or against others (Tweedy & Vanlandewijck, 2011). The functional classification process must be evidence-based and it must take into account the specific factors influencing the result in each sport (Tweedy, Gavin, & Bourke, 2010). In swimming, the International Paralympic Committee (IPC) establishes a functional classification system that combines the conditions of limb loss, cerebral palsy, spinal cord injury and other disabilities (International Paralympic Committee, 2015). Athletes are grouped in different numbered classes where a lower number indicates a more severe activity limitation than a higher number. For example, S1/SB1 swimmers demonstrate a significant

CONTACT Santiago Veiga santiago.veiga@upm.es

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loss of muscle power or control in legs, arms and hands (usually caused by tetraplegia and using a wheelchair in daily life), whereas S10/SB9 swimmers present minimal physical impairments (for example, the loss of one hand or a movement restriction in one hip joint). According to the type of impairment, swimmers with locomotor disabilities compete in one of the ten S classes established for the freestyle, butterfly and backstroke events and one of the nine SB classes established for breaststroke. For the swimmers with visual impairments, groups are divided into three functional S classes for the freestyle, butterfly and backstroke (S11, S12 and S13) and one of the three SB classes for breaststroke, depending on the degree of visual acuity, field of vision and light perception. Finally, swimmers with intellectual impairment compete under one S (S14) or one SB (SB14) class for the freestyle, butterfly and backstroke or breaststroke events.

The analysis of swimming competitions in Paralympic swimmers is based, in the same way as for the able-bodied competition, on a deterministic model (Hay & Guimaraes, 1983) where the total race time is divided in different race segments. The start time is measured from the beginning of the race to the swimmers' head reaching the 10 or 15 m mark from the wall; the turning time is measured between the swimmer's head reaching the 7.5 m mark (or similar distances like 10 or 15 m) before and after the turning wall; and the free swimming time is considered as the total race time minus the start and turn times, both in Olympic (Arellano, Brown, Cappaert, & Nelson, 1994) and Paralympic swimming (Daly, Malone, Smith, Vanlandewijck, & Steadward, 2001). The free swimming segment is the most important of the segments to the end result as, quantitatively, it represents the major contribution to the race distance. However, the start and turn times of swimmers with and without a disability are also correlated to their race performance to a very large extent, regardless of the stroke event (Daly et al., 2001; Veiga, Mallo, Navandar, & Navarro, 2014b). The ability of Paralympic swimmers to perform in the different race segments varies according to the degree of impairment, although those swimmers with similar physical limitations obtain similar 15 m starting or turning times despite belonging to different functional groups (Dingley, Pyne, & Burkett, 2014a).

In the last few years, new procedures have been developed to further analyse the swimming races of able-bodied competitors. Some research studies have measured the individualised starting and turning distances from the starting or turning wall to the point of the swimmer's head surfacing after swimming underwater. In this way, the real contribution of the non-swimming segments (start and turn) to the total race distance (maximum 24% in 100 m races) has been reported (Veiga, Cala, Mallo, & Navarro, 2013; Veiga & Roig, 2015) and higher level swimmers have been observed to travel longer distances underwater, which also seem to be dependent on the stroke event or gender (Veiga, Cala, Frutos, & Navarro, 2014a). As the underwater swimming represents the race segment with the fastest velocity (Vennell, Pease, & Wilson, 2006), small changes to the start or turn contribution to the race distance represent improvements of practical importance on the race performance at the elite level (Veiga, Roig, & Gómez-Ruano, 2016). In testing conditions, this individualised approach has also been employed to evaluate the freestyle swim-starts of Paralympic swimmers, indicating that duration of the underwater swimming depends on the severity of the swimmer's impairment but also on the type of impairment. Swimmers with upper body disabilities appear to spend a greater amount of time underwater in comparison to swimmers with lower body or palsy disabilities (Dingley et al., 2014a). Also, swimmers belonging to the least physically impaired groups (S9–S10) show no significant differences in a majority of the start subsections parameters (Burkett, Mellifont, & Mason, 2010). However, these individualised-distance race parameters have not been yet provided in Paralympic swimming, especially in the non-freestyle events.

Considering the diversity of impairments in Paralympic sport (Tweedy & Vanlandewijck, 2011) and the greater variability in the technical execution of Paralympic swimmers (Burkett, 2011), it is unknown how these swimmers configure the race distance in terms of underwater or surface movements or, at the same time, in terms of starting, free swimming or turning movements. Taking into account the practical importance of these race distances on swimming performance, the aims of the present research were (1) to characterise the individualised race segments configuration (start, turn and free swimming) of Paralympic swimmers and (2) to examine the influence of the swimmers' functional classification on their race segments configuration.

2. Methods

Five hundred and twelve finalists (248 men and 264 women) competing in all the functional classes of the 100 m events at the 2012 London Paralympic Games were analysed in the framework of a project to provide race analyses to coaches and swimmers during the competition. Table 1 shows participants in each functional classification group, as well as the race times of each event, noting that there were some classes with no 100 m events for a given swimming stroke (for instance, in S14 classes, only breaststroke and backstroke events for both genders were included in the programme of the 2012 London Paralympic Games). In order to reduce sampling variation along all classes of the Paralympic Swimming event, all swimmers were distributed for analysis in five Paralympic subgroups according to Fulton, Pyne, Hopkins, and Burkett (2009): S2–S4, S5–S7, S8–S10 (most through least physically impaired), S11–S13 (most through least visually impaired) and S14 (intellectually impaired). This approach reduced the uncertainty of inferences in the population of Paralympic swimmers (Dingley, Pyne, & Burkett, 2015), specially for comparison purposes (Dingley, Pyne, & Burkett, 2014b). All team managers provided an informed written consent before the commencement of the competition to employ race analysis for research purposes and all experimental procedures were reviewed and approved by the Institutional Review Board of the University. Due to technical reasons beyond the authors' responsibility, no race data were obtained from the men's 100 m butterfly S8 and breaststroke SB11 events.

Three fixed JVC®GYDV500E camcorders recording simultaneously at 25 Hz on the public stands of the London Aquatic Centre (at 10 m above and 15 m away from the side of the pool) were employed to record the 100 m final races, in accordance with previous race analysis studies in Olympic Games (Arellano et al., 1994). Each camera captured a different segment of the race: camera 1 captured from the starting block to 15 m, camera 2 captured from 20 to 30 m and camera 3 from 35 to 50 m. All three cameras were connected to a host computer via a GigE Vision compliant Gigabit Ethernet interface (Mare®, Technical University of Madrid, Spain) and race footage from each camera was stored in the same video file. The time code was determined by start light output connected to the official timing system.

2D-DLT algorithms Abdel-Aziz and Karara (1971) were employed to reconstruct the plane of motion during swimming races after a computerised analysis of images with manual digitisation (Photo 23D®, Technical Madrid University, Spain) was performed. Twenty-four

Table 1. Swimmer participants and end race times (mean ± standard deviation) in the 100 m races at the 2012 London Paralympic Games.

		Freestyle		Backstroke		Breaststroke		Butterfly	
Paralympic subgroup		Female	Male	Female	Male	Female	Male	Female	Male
S2–S4	*N*	8	12			8	8		
	Race times (s)	131.61 ± 18.10	105.63 ± 28.39			117.77 ± 9.20	103.43 ± 7.79		
S5–S7	*N*	24	28	16	16	24	24		
	Race times (s)	79.42 ± 6.25	69.86 ± 6.82	88.18 ± 3.64	76.73 ± 5.50	106.43 ± 8.55	90.55 ± 8.24		
S8–S10	*N*	24	24	24	24	16	16	16	8
	Race times (s)	65.37 ± 3.25	56.52 ± 2.72	75.17 ± 5.39	65.06 ± 3.68	82.69 ± 4.36	71.19 ± 3.79	71.79 ± 3.12	59.81 ± 2.03
S11–S13	*N*	24	24	16	24	24	16	8	24
	Race times (s)	65.32 ± 5.01	56.49 ± 4.73	78.65 ± 6.04	65.17 ± 4.39	85.98 ± 6.99	69.11 ± 2.78	71.53 ± 4.40	61.82 ± 4.36
S14	*N*			8	8	8	8		
	Race times (s)			70.62 ± 1.69	65.24 ± 1.64	82.42 ± 2.80	69.98 ± 2.26		

Notes: Class S2–S10 (most through least physically impaired); Class S11–S13 (most through least visually impaired); Class S14 (intellectually impaired).

pool building marks distributed along the swimming pool (eight marks per camera) were recorded by the three cameras and were used for calibration procedures. The accuracy of 2D-DLT calculation was assessed by reconstructing the position and distance between 32 other control points separated from the original calibration points and represented by coloured points on the floating lanes. The root mean square error of the 2D-DLT technique was 0.041 m when reconstructing the position of the 32 control points, and 0.037 m when reconstructing the distance between them. In order to quantify the race segments, the swimmers' hand entry or head surfacing were identified by an experienced observer at selected instants during the race. To assess the digitising process, the two technical actions defining race parameters (head surfacing and hand entry) were repeatedly digitised 32 times (four in each lane) in a randomly selected trial, with a coefficient of variation between 0.65% in lane 2 and 1.24% in lane 8. As expected, accuracy of digitisation was lower in the furthest lane from the camera position although error values were in line with previous studies (Veiga, Cala, González Frutos, & Navarro, 2010).

Once the position of swimmers at specific instants of the race was calculated, the following race parameters were obtained: dive distance (from the starting wall to the swimmer's first water contact after leaving the starting block), underwater distance (from the swimmer's first water contact to the swimmer's head surfacing from underwater), turn-in distance (from the swimmer's head position at the last stroke hand entry, or last head surfacing in breaststroke-to the turning wall) and turn-out distance (from the turning wall to the swimmer's head surfacing from underwater). In cases when the swimmers performed a push start from the water, no dive distances were computed. The sum of the dive and underwater distances of each swimmer represented the start distance, the sum of the turn-in and turn-out distances represented the turn distance and the total race distance minus the start and turn distances represented the free swimming distance.

A descriptive analysis of the variables (mean ± standard deviation) was firstly performed by gender and by class. Then, in order to examine the effects of the functional classification on the different races configuration, a repeated measures analysis of variance (ANOVA) was performed with the start and turn parameters according to the swimmers assigned Paralympic subgroup, the stroke and the gender. After ensuring the sphericity assumption was not violated and according to significant interactions with the Huynh-Feldt correction, multiple comparisons between the ANOVA levels were performed using the Bonferroni *post hoc* test. Alpha level was set at 0.05 for all the statistical tests and effect sizes (as partial eta-squared and Cohen's d values) as well as 95% confidence intervals (CIs) were used to provide an indication of the magnitude of the differences. The threshold values for trivial, small, medium and large effect sizes according to Cohen (1992) were 0.2, 0.5 and 0.8, respectively. All the analysis was conducted with SPSS 15.0 (SPSS Inc., Chicago, IL, USA).

3. Results

The start and turn segments configuration of Paralympic swimmers in different functional subgroups are shown in Tables 2 and 3, according to stroke and gender. Male swimmers generally travelled 1.12 m (95% CI 0.68 to 1.48 m, $p = 0.001$, $d = 0.33$ [small]) and 1.23 m (95% CI 0.83 to 1.48 m, $p = 0.001$, $d = 0.42$ [small]) longer start and turn distances, respectively, compared to female swimmers. Dive distances in backstroke events were shorter than in the breaststroke (−0.43 m, 95% CI −0.56 to −0.30 m, $p = 0.001$, $d = 0.71$ [medium]),

Table 2. Start segment configuration in metres (mean ± standard deviation) of the 100 m finals at the 2012 London Paralympic Games for the different subgroups.

Paralympic subgroup	Race segment	Freestyle		Backstroke		Breaststroke		Butterfly	
		Male	Female	Male	Female	Male	Female	Male	Female
S2–S4	Dive	1.98 ± 0.50	2.06 ± 0.45			1.62 ± 0.52	1.62 ± 0.52		
	Underwater	1.27 ± 1.38	0.96 ± 1.26			2.16 ± 1.53	2.16 ± 1.53		
	Total	3.25 ± 1.22	3.02 ± 1.12			3.78 ± 1.84	3.78 ± 1.87		
S5–S7	Dive	2.57 ± 0.50	2.17 ± 0.29	2.32 ± 0.31	2.00 ± 0.37	2.60 ± 0.57	2.28 ± 0.46		
	Underwater	3.42 ± 2.65	2.63 ± 1.56	3.80 ± 3.78	4.05 ± 3.95	5.95 ± 2.05	4.66 ± 1.56		
	Total	5.99 ± 2.98	4.80 ± 1.77	6.13 ± 3.79	6.05 ± 3.93	8.54 ± 2.42	6.94 ± 1.75		
S8–S10	Dive	3.32 ± 0.25	2.73 ± 0.25	2.29 ± 0.58	2.08 ± 0.43	3.28 ± 0.19	2.85 ± 0.25	3.40 ± 0.24	2.82 ± 0.27
	Underwater	6.18 ± 1.61	5.42 ± 1.51	6.34 ± 3.29	5.52 ± 2.66	8.24 ± 1.07	7.64 ± 1.10	7.04 ± 0.91	7.52 ± 1.10
	Total	9.41 ± 1.63	8.15 ± 1.62	8.64 ± 3.30	7.60 ± 2.78	11.52 ± 1.10	10.49 ± 1.14	10.43 ± 1.47	10.34 ± 2.09
S11–S13	Dive	3.09 ± 0.40	2.65 ± 0.44	2.74 ± 0.20	2.40 ± 0.14	2.83 ± 0.30	2.83 ± 0.30	2.98 ± 0.32	2.91 ± 0.29
	Underwater	6.71 ± 1.53	5.45 ± 0.98	8.12 ± 2.52	6.13 ± 2.50	9.35 ± 1.04	6.98 ± 1.07	7.76 ± 1.83	7.33 ± 1.86
	Total	9.80 ± 1.64	8.10 ± 1.31	10.86 ± 2.63	8.53 ± 2.50	12.18 ± 1.11	9.81 ± 1.15	10.74 ± 1.78	10.24 ± 1.76
S14	Dive			2.10 ± 0.28	1.68 ± 0.22	3.19 ± 0.18	2.23 ± 0.40		
	Underwater			8.20 ± 1.89	6.92 ± 2.17	8.25 ± 0.44	7.06 ± 0.92		
	Total			10.30 ± 1.81	8.60 ± 2.11	11.44 ± 0.44	9.29 ± 1.12		

Notes: Class S2–S10 (most through least physically impaired); Class S11–S13 (most through least visually impaired); Class S14 (intellectually impaired).

Table 3. Turn segment configuration in metres (mean ± standard deviation) of the 100 m finals at the 2012 London Paralympic Games for the different subgroups.

Paralympic subgroup	Race segment	Freestyle		Backstroke		Breaststroke		Butterfly	
		Male	Female	Male	Female	Male	Female	Male	Female
S2–S4	Turn in	1.05 ± 0.24	0.75 ± 0.30			1.20 ± 0.47	0.74 ± 0.22		
	Turn out	2.32 ± 0.67	1.60 ± 0.64			3.65 ± 2.04	2.62 ± 1.02		
	Total	3.37 ± 0.78	2.35 ± 0.74			4.86 ± 2.00	3.36 ± 0.98		
S5–S7	Turn in	1.54 ± 0.62	1.34 ± 0.50	1.68 ± 0.52	1.48 ± 0.50	1.32 ± 0.56	1.20 ± 0.43		
	Turn out	3.09 ± 1.52	2.82 ± 0.90	4.46 ± 2.07	4.01 ± 1.62	5.60 ± 1.90	4.32 ± 1.22		
	Total	4.63 ± 1.92	4.16 ± 1.15	6.14 ± 1.95	5.49 ± 1.68	6.93 ± 2.18	5.52 ± 1.22		
S8–S10	Turn in	2.39 ± 0.41	2.04 ± 0.44	2.47 ± 0.68	2.26 ± 0.44	1.65 ± 0.36	1.88 ± 0.51	1.21 ± 0.36	1.24 ± 0.40
	Turn out	3.68 ± 2.74	4.50 ± 1.04	6.75 ± 2.53	5.41 ± 1.43	8.31 ± 1.00	7.11 ± 0.82	7.41 ± 1.57	6.30 ± 1.25
	Total	6.07 ± 2.85	6.54 ± 1.22	9.22 ± 2.68	7.68 ± 1.51	9.96 ± 1.12	8.99 ± 0.84	8.62 ± 2.22	7.54 ± 1.32
S11–S13	Turn in	1.93 ± 0.59	1.71 ± 0.47	2.35 ± 0.57	1.83 ± 0.74	2.02 ± 0.45	1.64 ± 0.36	1.45 ± 0.56	1.72 ± 0.39
	Turn out	5.34 ± 1.42	4.48 ± 0.71	7.05 ± 1.75	5.12 ± 1.09	8.87 ± 0.92	6.43 ± 1.57	6.61 ± 1.56	6.11 ± 1.15
	Total	7.28 ± 1.66	6.19 ± 1.04	9.40 ± 2.06	6.94 ± 1.62	10.89 ± 1.00	8.07 ± 1.55	8.06 ± 1.72	7.83 ± 1.41
S14	Turn in			1.99 ± 0.42	2.14 ± 0.40	1.95 ± 0.20	1.76 ± 0.48		
	Turn out			6.27 ± 1.37	6.30 ± 1.51	7.91 ± 0.52	7.09 ± 1.31		
	Total			8.27 ± 1.67	8.45 ± 1.48	9.86 ± 0.51	8.85 ± 0.67		

Notes: Class S2–S10 (most through least physically impaired); Class S11–S13 (most through least visually impaired); Class S14 (intellectually impaired).

freestyle (−0.36 m, 95% CI −0.48 to −0.23 m, $p = 0.001$, $d = 0.69$ [medium]) and butterfly (−0.83 m, 95% CI −1.00 to −0.65 m, $p = 0.001$, $d = 1.34$ [large]) races, whereas the underwater distances on freestyle were shorter than the backstroke (−2.16 m, 95% CI −2.84 to −1.46 m, $p = 0.001$,$d = 0.54$ [medium]), breaststroke (−2.26 m, 95% CI −2.94 to −1.59 m, $p = 0.001$, $d = 0.93$ [large]) and butterfly (−3.43 m, −4.36 to −2.49 m, $p = 0.001$, $d = 1.37$ [large]) events. For the turn subsections, the turn-in distances in the backstroke events were longer than in the freestyle (0.43 m, 95% CI 0.29 to 0.60 m, $p = 0.001$, $d = 0.55$ [medium]), breaststroke (0.49 m, 95% CI 0.32 to 0.66 m, $p = 0.001$, $d = 0.83$ [large]) and butterfly (0.62 m, 95% CI 0.39 to 0.85 m, $p = 0.001$, $d = 0.98$ [large]) races whereas, on the turn-out phase, freestyle distances were shorter than the remaining events (−2.18 m, 95% CI −2.68 to −1.67 m, $p = 0.001$, $d = 0.93$ [large] in backstroke, −2.60 m, −3.10 to −2.11 m, $p = 0.001$, $d = 1.06$ [large] in breaststroke and −3.10 m, −3.80 to −2.42 m, $p = 0.001$, $d = 1.24$ [large] in butterfly). When start and turn distances were computed together, the contribution of the non-swimming segments to the 100 m Paralympic races varied between 6 and 8% for the S2–S4 subgroup, 11–15% for S5–S7, 15–21% for S8–S10, 15–23% for S11–S13 and 17–21% for S14.

The 100 m race segment configuration of Paralympic swimmers depended on their functional classification group ($F_4 = 109.47$; $p = 0.001$; $\eta^2 = 0.48$), as the S8–S10 swimmers travelled 1.45 m longer distances (95% CI 1.14 to 1.76 m, $p = 0.001$, $d = 0.59$ [medium]) than S5–S7 swimmers during the non-swimming parts of the race, and these travelled 1.23 m longer distances (95% CI 0.76 to 1.70 m, $p = 0.001$, $d = 0.63$ [medium]) than S2–S4 swimmers. On the other hand, no differences in the non-swimming distances were observed between the S8–S10 swimmers and the S11–S13 (−0.13 m, 95% CI −0.43 to 0.17 m, $p = 0.999$, $d = 0.06$ [trivial]) and S14 (−0.25 m, 95% CI −0.73 to 0.24 m, $p = 0.999$, $d = 0.06$ [trivial]) swimmers. The only exception were the shorter dive distances travelled by S14 swimmers compared to the S11–S13 (−0.44 m, 95% CI −0.65 to 0.23 m, $p = 0.001$, $d = 0.92$ [large]) and the S8–S10 swimmers (−0.41 m, 95% CI −0.62 to 0.20 m, $p = 0.001$, $d = 0.56$ [medium]). The influence of the functional classification group on the 100 m race segment configuration showed few differences depending on the stroke ($F_7 = 1.333$; $p = 0.23$; $\eta^2 = 0.02$) or the gender ($F_4 = 2.151$; $p = 0.07$, $\eta^2 = 0.02$) of the swimmers.

4. Discussion

The functional classification system in Paralympic swimming must be evidence-based in order to understand the influence of the athlete's impairment on his/her performance. In the present research, the individualised-distances travelled by Paralympic swimmers with their starting, turning and free swimming movements were measured to evaluate the differences between functional classes. The start and turn distances showed no difference between the least physically impaired, the visually impaired and the intellectually impaired swimmers (S8–S10, S11–S13 and S14 subgroups), although differences in the race segments were observed between the three subgroups of swimmers with physical impairments. Therefore, in terms of the race segment distances, there is no evidence to classify S8 to S14 swimmers in different functional classes.

To the best of our knowledge, this study represents the first time that race analysis based on individualised-distances has been applied to Paralympic swimmers. The first important observation is that the race segments in the Paralympic 100 m swimming events are far from the traditional 10 or 15 m distances for all the functional groups of swimmers (Tables 2 and 3). Distances on the start and turn segments did not surpass the 5 m mark in any of the S2–S4 swimmers nor the 10 m mark in the remaining classes, except in the start segment (non-freestyle) of selected S11–S13, S14 or S8–S10 events. The maximum contribution of the start and turn to the total race exceeded 20% of the 100 m just on the S8–S10 (21.5 ± 2.06%), S11–S13 (23.1 ± 1.72%) and S14 (21.3 ± 0.79%) breaststroke male races and on the S11–S13 (20.3 ± 4.59%) male backstroke races. This is a much lower percentage than the 30% distance of the 15 m procedure or the percentage of 15 m starting and turning times employed by Paralympic swimmers with visual impairment (Daly, Malone, Burkett, Gabrys, & Satkunskiene, 2009). Differences were partly explained by the different types of start employed by competitors according to their specific impairment. For example, the S2–S4 swimmers began the race from a push start and travelled start distances (from the wall to the swimmer's head surfacing) shorter than 5 m, which represents a clear difference to the 10 or 15 m mark. Also, swimmers competing in S6 class races were affected by amputations of both arms, moderate co-ordination problems on one side of their body or short stature (International Paralympic Committee, 2015) and employed a push start or a dive start from a seated or standing position on the block. This variability was represented by maximum values of standard deviation in the start distances on these classes (Table 2) and it would suggest the use of individual distances to effectively evaluate their non-swimming race skills (Puel et al., 2012) or, at least, that race analysts would adapt the starting and turning distance references to the functional characteristics of these Paralympic swimmers. Presently, the individual distances have only been employed to describe the dive and underwater distances of Paralympic swimmers when testing freestyle starts (Burkett et al., 2010; Dingley et al., 2014a) and values have been similar to those observed during the 2012 London Paralympic Games (Tables 2 and 3). However, no other individualised data on a race situation was found on the literature.

The distribution of the 100 m race segments during 2012 London Paralympic Games showed a trend between the different functional groups of swimmers, where the start and turn distances increased according to the lower degree of impairment (from lower to higher classes). This was partly in line with previous studies where swimmers with high-severity impairments spent a smaller percentage of time swimming underwater (Dingley et al., 2014a) and it is attributable to the reduced kicking capacity of these swimmers (Fulton, Pyne, & Burkett, 2011). For example, S2–S4 classes have reduced functional potential in the lower and/or upper limbs due to tetraplegia below C8, musculoskeletal impairment comparable to complete tetraplegia below C8 or severe dysmelia of three limbs (International Paralympic Committee, 2015). As the kicking is the main method of propulsion in the underwater phase, the surface swimming would represent a more efficient technique for them to improve average velocity. However, we observed some distance overlap between classes, as previously observed for the start and turn times (Daly et al., 2001; Dingley et al., 2014a) or the start subsections (Burkett et al., 2010) and distances travelled for a lower subgroup were not shorter than distances travelled on the superior subgroup (Tables 2 and 3). This was especially evident for the least physically impaired, the visual impaired and the intellectual impaired swimmers (S8–S10, S11–S13 and S14 subgroups), where no differences in the start, turn and swimming distances were observed (also regardless of the stroke or gender). Previously, these groups had been observed to perform similar 15 m starting times (Dingley et al., 2014a). Probably, for these swimmers, the physical requirements for the start and turn execution such as core strength, upper limb strength or lower limb strength did not depend on the nature and severity of the underlying physical, visual or intellectual impairment (Dingley et al., 2014b). Also, according to our data, their end race times showed marginal time differences (Table 1). Therefore, from this race configuration perspective, there would be no evidence to classify them in different functional groups. Previous studies have also found analogous performance levels between elite S10 and S13 swimmers on the 400 m freestyle events (Taylor, Santi, & Mellalieu, 2016) and have suggested an integrated competition of these functional groups.

Compared to able-bodied swimmers, the contribution of the non-swimming components in the Paralympic races showed differences depending on the degree of impairment and also the level of performances. For the higher classes of Paralympic swimmers (S8–S10, S11–S13 and S14), start and turn distances were similar to those previously reported in able-bodied competitive swimmers at regional and national level (Veiga et al., 2014a) which is in line with their similar point scoring on the overall race times (between 500 and 700 FINA (Federation Internationale Natation) points for both groups). Values for the subsections of the turn segment (in and out distances in Table 3) were also similar to those reported by Veiga et al. (2014b) for national male competitors. However, for elite able-bodied swimmers competing at the World Championships, the start and turn distances were approximately 2 m longer than the high classes of Paralympic swimmers, especially in the butterfly and backstroke events (Veiga & Roig, 2015). Also, Olympic swimmers obtained longer underwater distances in the freestyle starts than Paralympic swimmers with a low degree of physical impairment (Burkett et al., 2010). Probably, the technical complexity of the undulatory movements and the high levels of muscle and joint flexibility required as well as stability and control of muscles (Atkinson, Dickey, Dragunas, & Nolte, 2014) could explain differences. On the other hand, the start and turn distances of swimmers with a higher degree of physical impairment (S5–S7 and S2–S4 classes) were lower than those reported in able-bodied swimmers regardless of stroke and performance level. For these swimmers, the severity of their impairment represented a limitation in terms of drag resistance (Oh, Burkett, Osborough, Formosa, & Payton, 2013), the application of impulse forces or the kicking propulsive force application (Dingley et al., 2014a) to perform the underwater swimming. Indeed, the majority of swimmers in the S5–S7 and S2–S4 subgroups travelled shorter underwater distances than the dive distances when starting the race (Table 2).

The results of the present research could serve as a benchmark for elite coaches and swimmers in order to distribute their race segments distances according to the event, the level of performances and/or the swimmer functional classification group. Of course, the underwater distances should be individualised according to the degree and nature of swimmer impairment but coaches should seek areas of improvement on the underwater undulatory skills, where great differences are observed between Paralympic and able-bodied swimmers. Also, results from the 2012 London Paralympic Games could serve race analysts as a frame of reference for the race segments of Paralympic swimmers. This would allow them to perform a more specific evaluation of the non-swimming skills in a race or a testing situation. A limitation of the present research was that average velocity values during the swimming race segments were not provided. This would allow readers to examine the effect of the start and turn distances on the end race results. In the future, new researches in Paralympic Swimming would be needed to provide more information about this issue.

5. Conclusions

Race segments distances travelled by swimmer finalists in the 2012 Paralympic Games suggest new challenges to the system of Paralympic classification as no evidence was found to classify high physically, intellectually and visually impaired swimmers in different functional groups. The starting and turning distances of the 100 m events tended to increase in swimmers from low to high functional classes due to the limitations of their specific impairment but no differences were observed between competitors with a lower degree of physical impairment (S8–S14). New procedures based on individual distances could be added to evaluate the race segment configuration of Paralympic swimmers as great discrepancies with the traditional 10 or 15 m start and turn distances were observed.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Archit Navandar http://orcid.org/0000-0001-6997-8099

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