FUNCTIONAL INFORMATION FOR PARALYMPIC SWIMMERS

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Swimming competition for persons with a loco-motor disability is organised according to a functional classification system. However, until the Atlanta Paralympic Games, these swimmers had never been the subject of a more extensive race analysis. Information from this analysis, which could be of interest to coaches of able bodied as well as disabled swimmers, has been discussed. In general Paralympic swimmers do not start, turn, or finish their race much different from Olympic swimmers. The relation of stroke rate and length with free swimming speed is also similar. However, some exceptions within specific impairment groups have been found.

KEY WORDS: swimming, paralympics, race analysis

INTRODUCTION: Swimming competition for persons with a loco-motor disability is organised according to a functional classification system. Swimmers are placed into a class according to scores on muscle testing, range of motion tests, co-ordination and/or level of amputation. A water test of the swimming strokes as well as starting, turning, and buoyancy is also made. One combination of tests is used to classify the freestyle, backstroke and butterfly events (the S classes) and another combination is used for breaststroke (the SB classes). Swimmers with varying impairments compete together in any one class but the distribution of impairments over classes is not fixed. Due to considerations of medical ethics, the individual impairment profiles are not generally made public.
Since 1988, video recordings have been made from above water during the swimming events at Olympic games. Using these recordings, performance and stroking variables (e.g. starting and turning time, stroke length (SL), and rate (SR)) were measured and the results provided to swimmers and coaches in addition to race results and common split times. In cooperation with researchers at the Atlanta Olympic Games the same video recordings were made for the first time during the 1996 Paralympics swimming events.
Previous to the project discussed here, in Paralympic swimming, performance analysis had been done of the End Race Result (ERR) (Wu & Williams, 1999; Daly & Vanlandewijck, 1999). However, only one group (Pelayo et al., 1996; Pelayo, Sidney, Moretto, Wille & Chollet, 1999), has made a more in depth analysis investigating SR and SL. Even in that study only race mean values were given and only one event (100m freestyle at a European Championship) was studied. Other race segments such as starting, turning and finishing were not examined.
Therefore, the purpose of this study was to provide coaches and swimmers with additional data on how the best Paralympic swimmers obtain speed. A secondary purpose was to monitor the functional classification system using more information than is provided by only the ERR. As a result of the work done until now these authors have also been able to obtain more detail on the individual impairments of the swimmers. Some preliminary findings based on this information will also be reported in this paper. Furthermore, recently we have started testing top-level disability swimmers in a swimming flume. Some discussion of these findings is also presented.

METHOD: With the approval of the International Paralympic Committee, Sports Assembly Executive Committee for Swimming, Swimming Science Committee, the preliminary heats of all events were recorded on video for all men and women at the 1996 Paralympics. The same was done for the 1996 Olympic finalists and consolation finalists (N=16 men & 16

women), (IOC, 1996). Methods used have been reported at previous Symposia of Biomechanics in Sport (Malone, Daly, Vanlandewijck & Steadward, 1998). The following variables were available: clean swimming speed (CSS) per 25m race segment, start time (ST), finish time (FT), and turn times (TT). In addition, stroke rate (SR) and stroke length (SL) were measured during each race lap. When arm movements could not be seen from above water, bobbing actions and/or breathing frequency was used to estimate SR.
Two sets of point scores were calculated for the ERR:

(a) To compare the performance level between classes over the same swimming distance and between distances for the same class, the swimming times were converted to a point score. The point system is based on a function in which the World Record (WR) for each event - gender, stroke, class and distance - receives 1000 points (Van Tilborgh, Daly, Vervaecke & Persyn, 1984). A constant ($\mathbf{C}_{event}$) specific to each event can be calculated as follows:

$$\mathbf{C}_{event} = WR^{(3)}_{event} * 1000.$$

When all the constants are known, each individual time can be assigned a point score specific to the event:

$$\text{Individual Performance Point} = \mathbf{C}_{event} * \text{Individual Event TIME}^{(-3)}$$

(b) To obtain a more normal distribution of the performance results, required to run some statistical applications, all swimming times were also converted to a second point score, always using the Constant for class S10 (Class 10 point score).

To make comparisons of race segment times among classes, indexes were calculated. These relate time or point score for a segment (ST, TT, FT) to the ERR or CSS in percentage terms. To calculate the point scores for use in the indexes, the Constant for class 10 was always used.
In the 400m event various race variables such as CSS, TT and SL could be measured several times over the race. The standard deviation of the mean of such a variable reflects race evenness. In other indexes the value of the final occurrence of a variable was subtracted from the mean value or the value of the first occurrence.
Presently, information is also available on the individual impairments for the male 100m freestyle participants in Atlanta. There is a wide range of impairments within these 159 swimmers. For the purpose here they were categorized into Arm Swimmers (= e.g. leg amputees), Leg Swimmers (e.g. = dysmelia[(1)] arm), Spinal Cord Injured, Cerebral Palsy[(2)] and Polio. For the moment Arthrogryposis[(3)] was considered separately. SAS software was then used for further statistical analysis.
Finally, three top-level swimmers with a disability (at least European championship finalists) were also recently tested in a swimming flume. The athlete performed a series of submaximal 3-minute swims at the same speed with or without weights assisting or hindering forward movement (step test). This is a protocol described by Pendergast, di Prampero, Craig Jr., Wilson, & Rennie, (1977) and leads to an estimation of active drag and thus swimming efficiency. A maximum fatigue swim was also performed. During the swims in addition to the collection of expired air, video recordings were made. Surface electromyography was also done for 7 muscles (groups) on both left and right hand sides of the trunk and arms.

RESULTS AND DISCUSSION: As has been discussed elsewhere (Daly, Malone, Vanlandewijck & Steadward, in press) very little extra information can be obtained for the coach from the ERR other than what he already knew a long time ago. However, classification fairness can be discussed. One would expect, for example, that the mean ERR as well as the time of the first place finisher will decrease with functional class. This is generally the case in all the 100m and 400m(free) Paralympic events confirming the validity and thus the credibility of the system.

Another point of discussion is comparison of performances among classes. This is a fundamental problem for those responsible for Paralympic selection. There is now a quota per country on the number of Paralympic participants based on the number of swimmers that country has in the top 12 of the world ranking lists. The number of men and women per country is also fixed but the class distribution is not. If the choice needs to be made between two potential medal winners, the person with a time that is relatively closest to the class world record will be selected. On this basis the lower classes are at a disadvantage.

A closely related point of discussion is the competitive level of the various impairment groups, which make up any single class. Do they all have an equal chance of winning? With regard to the 100m free event for men the Polio group was the least competitive. The difference was not significant, however, possibly due to the low number of swimmers with Polio. Indeed, these participants for the most part compete in lower classes, which are, on the whole, less competitive. Wu & Williams (1999) have previously discussed Polio athletes with regard to the lower numbers of medals that this group won.

Another reason for examining the general competitiveness of functional classes is to determine if it is valid to compare relative race segment times (e.g. starting or turning) between Olympic and Paralympic swimmers and among Paralympic classes. We have previously shown, based on the point score described, that the competitive level of the higher Paralympic classes in the 100m events in men is quite similar to that of the Olympic events. This indicates that such comparisons are at least reasonable (Daly, Malone, Vanlandewijck & Steadward, 1999a).

Table 1 Number of Male 100 m Freestyle Participants According to Paralympic Functional Classes and Impairment Group

	Oly	S10	S9	S8	S7	S6	S5	S4	S3	S2
Men	16	24	21	25	26	18	13	14	11	6
Women	16	11	22	10	16	18	8	8	8	6

	Olympic	Arm	Leg	Cerebral	Spinal	Polio	Arthrogry
Dive	16	32	31	25	13	11	1
No Dive		1	3	18	14	5	5

Relative Race Segment Times: The segment times are used to determine which part of the race most determines the ERR. As expected, the CSS ($\pm$.90) correlates highest with race success. Nevertheless, in classes where swimmers who can dive start and push off well are mixed with those who cannot or do not dive, the divers appear to have an advantage in freestyle as well as in breaststroke.

When the starting speed is compared to the swimming speed of the first race segment in breaststroke, somewhat surprisingly, the higher Paralympic classes start relatively faster than Olympic swimmers do. This is not the case for turning in which much more actual swimming is involved (7.5m in and out of the turn). Actually, the Paralympic swimmers are not starting faster but are swimming slower. Paralympic swimmers can perform a relatively unskilled activity such as starting much better than they perform the much more complicated breaststroke. The findings for women confirm this as well as the fact that this does not occur in freestyle.

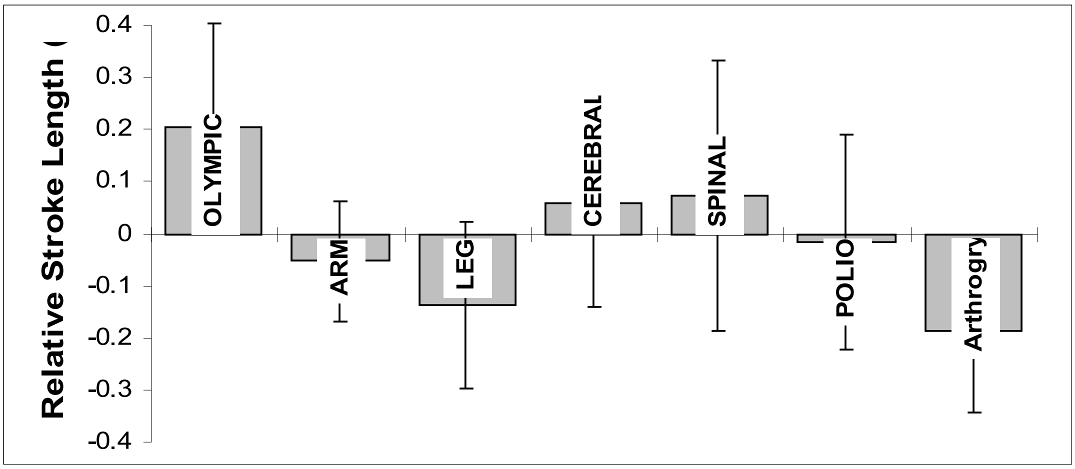

Figure 1 - Relative starting and turning speed for Olympic and Paralympic swimmers in the 100m freestyle.

In the impairment groups we see that Olympic swimmers (250%) start fastest with the Leg, Arm, and the Cerebral Palsy swimmers concentrated around 200% and the remaining impairment groups at 150% just behind them (Figure 1). The differences among these groups in turning are much smaller. The Leg (133%) swimmers turn fastest and the Arthrogryposis swimmers turn slowest (109%). Perhaps the difference between relative starting and turning speed is an indication of explosive leg strength. There is surprisingly no clear difference between divers and non-divers in these two parameters.

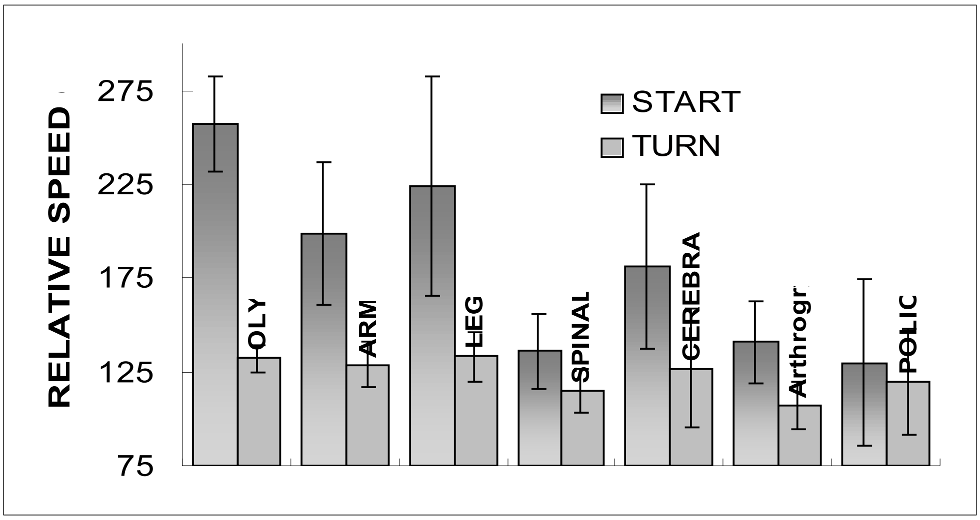

Figure 2 - Relative SL in Olympic and 6 impairment groups of Paralympic swimmers (residual score from regression line between CSS and SL).

Stroking Variables: In studies of Olympic swimmers SL was found to be more related to swimming speed than SR. (Arellano, Brown, Cappaert Nelson, 1994). This is also true for Paralympic freestyle swimmers. Nevertheless, when the individual changes in SR are observed in relation to changes in swimming speed within a 400m freestyle race, it was seen that individuals adjust their speed mainly by changing SR. The residual score from the regression line between CSS and SL (R^2=.68) is taken here as relative SL. Olympic swimmers clearly have the longest relative SL for their CSS (Figure 2). In other words they achieve their swimming speed with a low SR. In the past, this has been considered as an indication of technical efficiency (Costill et al., 1985). Within the impairment groups the CP swimmers and Spinal Cord Injured have a higher relative SL. Quite as expected because of the small upper limbs both the Leg swimmers and the Arthrogryposis swimmers have especially low relative SL. One must not forget that we are only speaking of freestyle for the moment and the picture for breaststroke should be different.

Cluster Analysis for Stroking Variables: A question is if there are groups of swimmers who achieve the same CSS but with separate combinations of SL and SR. Performing cluster analysis on Paralympic swimmers, 3 clear groups of 100m freestyle participants were found in men. The first (n=94) had a mean SR and a long SL, the second (n=34) a lower SL and a very low SR and the third (n=19) a low SL and a mean SR. The first group contained all Arm swimmers while the difference between clusters 2 and 3 is primarily in that 60% of cluster 2 where CP swimmers. CP swimmers thus generally all use a low SR and probably a stable SR as well.

400m Race Performance: The variables measured as well as indexes calculated could be useful in evaluating race strategy and determining how an individual won or lost the race. Attempts to quantify the evenness of race performance in 400m freestyle have been described in the methods section. There were, however, only a few significant correlations found between these variables and ERR and only in class S7. Apparently everyone at the (Para)Olympic level swims the race in an even manner. Nevertheless, correlations and means give only a general picture of what is happening. In fact, very few individuals actually follow the general pattern. For example, the women's Olympic winner in 1996 did not swim an ‘even’ race. She held the pace during the first 200m of the race and then sprinted ahead during laps 5 and 6 to hold on to her lead despite a slow finish. In Paralympic swimmers the winner was better in every aspect of the race after the start, while the second place finisher built up a lead over the third place finisher at the beginning of the race and held on to it. Of course, every coach has been collecting such information for him- or herself for years but not on such a wide scale. It is also noteworthy to mention that the mid-race sprint of the Olympic winner was associated with a decrease in SL and thus an increase in SR.

Medley Swimming: Very little is said about medley swimming in the biomechanics literature. In most popular books an entire chapter is devoted to each stroke while the individual medley event is hardly mentioned. Also, we only started to look at medley after all the individual strokes had been discussed. The classification for medley (SM classes) is based on a weighted combination of the SB (breaststroke) and S (other strokes) scores.

The competitive level of the 200m medley event in which classes SM5 and above compete Internationally is higher than all other events except the men’s 100m freestyle. This could indicate that only the very best swimmers compete, nevertheless there were actually relatively more competitors (men, N= 73, women, N=62) only in the 100m freestyle events. Thus, it is more likely that the Paralympic World Records from which the competitiveness score is based might be weaker than the other events. In fact of the 27 male participants in classes SM10 and SM9 only four did not also participate in at least two other 100m individual stroke events. Only one Olympic 200m individual medley A or B finalist also swam an A or B final in a 100m stroke event.

In Paralympic swimming both butterfly and freestyle (r=.66) speed were about equally important for medley ERR and breaststroke speed contributed the least to race success. There was little distinction in Olympic swimmers. Using cluster analysis it was also not possible to find groups of swimmers who were all particularly good in any one stroke. Individual results do show that most Paralympic and Olympic swimmers perform about equally well in all strokes with never more than one relatively weak or relatively strong stroke (Figure 3).

Not unsurprisingly there were few significant relationships between race mean SL and ERR and between the stroke specific SL and stroke CSS in either Olympic or Paralympic medley swimmers. The relationship among the stroke specific SLs and SRs are also not systematic over the functional classes. One difficulty might be that in this study medley SR is only measured once for each stroke (race lap) while in all individual stroke events SR is measured at least two times.

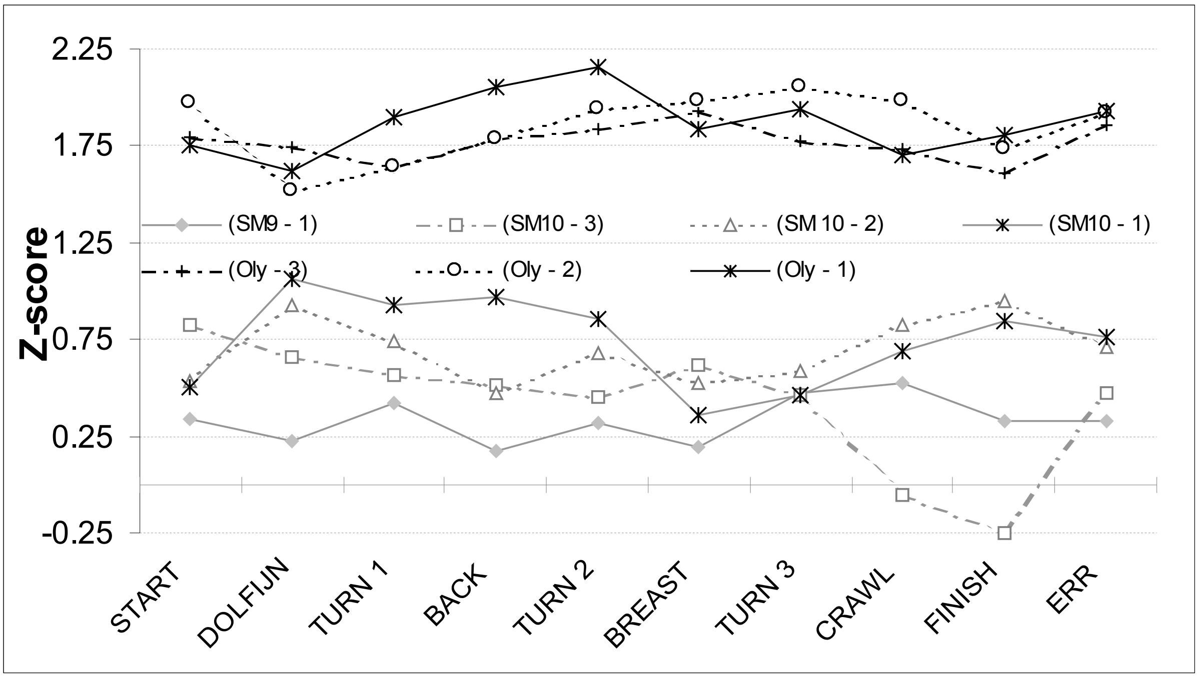

Figure 3 - Individual race profile for Olympic, and Paralympic (SM10 and SM9) male swimmers. The relative performance in each race segment is presented as a Z-score.

Swimming Efficiency: Several attempts have been made over the years to measure mechanical efficiency while swimming. One method has been described by Pendergast et al. (1977) and has been applied here with some adaptations in a swimming flume. The connection of the swimmer to the semi-tethered system has been improved by a belt system allowing body rotation around any axes. As an example, a top female athlete (Dysmelia, lower arm left) is taken here while breaststroking (best performance ± 1:30). During the 3 min swims at 0.7m/s the active drag was measured at 32.8 N and a power output (Pmech) estimated at 22.9 W. The overall-efficiency was estimated to be 2.85%, varying only by 0.27 % during the 3 steps. This indicates that adding or subtracting weight did not change the movement itself. The efficiency is nevertheless quite a bit lower than the value found for an elite male breaststroker and a single above knee amputee swimmer both at 0.8m/s as well as for this same swimmer performing the crawl stroke (around 4%).
The simultaneous coupling of electromyography and video analysis enables a phase specific allocation of muscle activity. The level of activity is categorised as no activity, slight, moderate or strong activity. The point of attention will of course be asymmetry in muscle activity. In this swimmer who is missing the lower half of the left arm, in general the erector spine and latissimus dorsi are the most active muscles of those sampled over the entire arm movement. Almost no asymmetry in the activity of these trunk muscles was seen. The deltoideus was least active but did show the greatest asymmetry. The right deltoideus showed constant slight activity during both spreading and bringing together of the arms, while the left side changed from moderate to no activity during these two phases. Asymmetry of activity was also seen in the triceps brachii with strong activity right side during the recovery phase and only moderate activity left. On the other hand, during the spreading

and bringing together the left triceps was more active. The video observation actually showed a narrow crawl like arm pull with both arms and not the more typical breaststroke sideward sculling like arm actions.

Of course this remains a case study but this type of analysis could lead in the future to increased knowledge of the relationship of size of propulsive surface to swimming efficiency. This information might also provide a clearer picture of the diversity of muscle activity possible among individuals performing what many considered to be the same swimming stroke.

CONCLUSION: There are probably far fewer differences between Olympic and Paralympic swimmers than one might have expected. Paralympic participants start, turn and finish the race in a similar manner to Olympic swimmers. Their SL also coincides with their CSS in most impairment groups. Nevertheless, from a biomechanical standpoint there is much to be learned about, for example, the influence of propulsive surface on swimming speed and efficiency from well-trained swimmers who just happen to be missing such a surface. Studying the possibilities to compensate for this lack of surface by using new movements and different muscles my also lead to a better understanding of how all swimmers achieve speed. Perhaps we should no longer use the term disability but in the future refer to all Olympic as well as Paralympic participants simply as swimmers.

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Glossary

(1) **Dysmelia:** Malformation of limb or limbs as a result of a disturbance in the embryonic development.

(2) **Cerebral palsy:** A non progressive disorder of movement and posture due to damage to an area, or areas, of the brain that control and co-ordinate muscle tone, reflexes posture and movement.

(3) **Arthrogryposis:** Congenital immobility of joints with limited movement or stiffness of one or more extremities with lack of muscle development and growth.

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