

Redefining Exercise Intensity during Competition Swimming



Emma Swanwick* and Martyn Matthews

University of Salford, School of Health Sciences, UK

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*Corresponding author: Emma Swanwick, School of Health Sciences, University of Salford, Frederick Road, Salford M6 6PU, UK

Abstract

Anaerobic contribution can quickly decrease, even in shorter time line events (20-30 sec, 200m running, 50m swimming). Previous authors have demonstrated aerobic contributions between 29 and 40% for various levels of athlete over this time course in a range of exercise types (Running, cycling swimming rowing). We have developed methods that demonstrate better clarification of systemic use and wished to understand these differences during competition conditions. 440 subjects (299 Male & 141 Female) volunteered to take part in this study and were drawn from a number of national events. Blood lactate and glucose were tested immediately post swim until a peak of each parameter was found. Swim time and stroke parameters were also collected for each swim. Data were collected in all event distances (50m 100m 200m 400m 800m & 1500m).

The generation of system contribution followed the methods of Swanwick & Matthews (2018). The comparison of contribution in male Freestyle events, 50m-100, showed significant differences in glycolytic and anaerobic contributions (P 0.0002), 100-200, anaerobic only (P 0.0002) and 400 to 1500m in aerobic and anaerobic (P 0.0002) Females showed less differences in system contributions (50-100, glycolytic, (P 0.01) and 200-400m (anaerobic, P 0.002). When glycolytic and anaerobic capacities were combined, our results were in agreement with Conclusion; The model has demonstrated values that are in line with previous authors but has greatly increased the possibility of understanding energy contribution differences through the identification of the importance of the glycolytic contribution during vigorous and maximal exercise.

Introduction

Observation of energy dynamics in swimming competition has been sparsely studied in recent years. Previously, when it has been studied, it has been limited to the study of lactate values at the end of races [1,2]. These studies demonstrated that peak lactate values decrease from the peaks in the 200m events (individual medley in particular) to the 800 and 1500m events, and that lactates are higher in older swimmers than younger swimmers. Although relationships between the velocity at 4mmol and the speeds of the distance events (400,800 and 1500m) have been established Bonafazi until Rodriguez and Mader (2003) little else has been noted in relation of energy contribution to the events. These authors used a combination of the analysis of post exercise breath-by-breath oxygen uptake after 100m and 400m maximal swims and a computer simulation to suggest that the aerobic contribution in both events was significantly higher (average 400m 84.4%, 100m 57.9%), than had been previously suggested in events on the same timescale.

These results were broadly in line with the findings of Laffite et al. [3] Hellard and his group (2005) looked at modelling the residual effects and saturation thresholds of Olympic swimmers and found

that identifying individual training thresholds might help develop performance. Their study however, recognized that, in this model, training variables still only accounted for 30% of the variation in performance. With the exception of these measures were not taken during competition, making their comparativeness less valuable. Anaerobic contribution can quickly decrease even in shorter time line events (20-30 sec, or 200m running equivalent) and our previous findings around this have tied in well with findings of other authors who have demonstrated aerobic contributions between 29 and 40% for various levels of athlete over this time course and with different modes of exercise including treadmill running @1% [4], Cycling [5], Medbo and Tabata [6] and running [7].

This is also the case over longer time lines used in competition swimming events Spencer et al. [8-11]. In athletic events, specific contributions of aerobic and anaerobic mechanisms have been identified in simulated competition efforts Duffield et al. [10] and Duffield et al. [12]. These have not been measured at competition, where the added element of the athlete working for a race position could change the energy outcome. Previously we have demonstrated methods for better identifying metabolic contributions to maximal efforts [12] and have demonstrated the changes that have occurred

during training. Briefly, this describes a need to view the function of the energy system split into 4 components (Aerobic oxidative, Aerobic glycolytic, Anaerobic glycolytic, Creatine phosphate – ATP) rather than 3 (Aerobic, Anaerobic Creatine phosphate-ATP). Using this as the basis for generating a model of assessment, it is possible to use the maximum lactate from an effort and predict at what level of blood lactate MVO_2 occurred. We would use this to define the point from which anaerobic capacity could be defined. Additionally, using the change in blood glucose, we proposed that it could be used to identify the amount of work that was met by aerobic glycolytic mechanisms.

From the combination of these two, we could then finalize the total aerobic contribution within a maximal effort. This model has been tested rigorously and found to be reliable. Pool swimming events last from 20 seconds (men’s 50m freestyle) to 16 minutes (women’s 1500m freestyle), so the contribution of energy can vary greatly. The type of aerobic contribution that makes up this growing percentage during maximal efforts can also vary depending upon the swimmers’ training background (Swanwick and Matthews 2018). This may provide vital differences in how a swimmer completes his or her performance that may greatly influence the

outcome in maximal effort competition efforts. This aspect of performance, to our knowledge has not been investigated under competition conditions.

Methods

440 subjects (299 Male & 141 Female) volunteered to take part in this study. Swimmers were competing at either the South African Olympic trials or the New Zealand world championship trials. Swimmers’ weight and percentage body fat were also assessed during this time (Table 1). Two blood samples of 25µl were taken from each swimmer, post-race completion and prior to starting their swim down, every 2 minutes until a peak of blood lactate and blood glucose was ascertained (between 2 and 10 minutes). At a later time, the results were plotted using the methods [13]. To assess the percentage of aerobic, glycolytic and anaerobic contribution to each swim. The testing process and analysis was reviewed and approved by the High Performance Centre (University of Pretoria South Africa) research ethics board and the Christchurch College of Education research ethics board (New Zealand). All participants provided both verbal and written confirmation of their consent to participate in the study. The study also adhered to the ethical standards of the South African Olympic committee.

Table1: Mass and percentage body fat of all subject per event.

	Males (n=299)		Females (n=141)	
	Mass (kg)	% Body Fat	Mass (kg)	% Body Fat
50m Events	84.47	9.1%	62.73	15.4%
SD	± 4.32	± 1.0%	± 9.82	± 1.6%
100m events	80.14	10.3%	62.91	17.9%
SD	± 1.43	± 1.6%	± 32.98	± 9.0%
200m events	77.75	10.2%	61.97	17.5%
SD	± 1.66	± 1.1%	± 3.93	± 1.1%
400m events	76.00	9.0%	60.80	19.4%
SD	± 2.42	± 1.6%	± 4.21	± 4.1%
800 & 1500m events	76.44	10.2%	63.75	14.8%
	± 3.71	± 2.2%	± 5.97	± 4.5%

Results

Event data is collated with means and standard deviations to show time (sec) Lactate (mmol/l), Glucose (mmol/l), Body mass (kg) & body fat percentage in Table 2. Mean Swim time, lactate and glucose for each distance are shown in Table 3. There were variations in the quality of swims recorded as some events were weaker than others. 50m Events near hear. Table 2 Fastest times for the males were in the 50 freestyle, and slowest in the 50 breast. Mean lactate was highest in the freestyle event, lowest in the 50m

butterfly, then breaststroke and backstroke. Glucose was lowest in freestyle and highest in breaststroke. Only the 50 freestyle was monitored for females. Both lactate and glucose were lower in females.100m events. In the 100m events, fastest swims were in the freestyle and butterfly. Both events had swimmers who achieved Olympic qualification. The slowest events were backstroke and breaststroke. Lactate was highest in freestyle, approximately 2mmol/l above that of butterfly and lowest in breaststroke and backstroke.

Table2: Mean and standard deviation of all male and female events tested (time (sec) Lactate (mmol/l), Glucose (mmol/l) Body mass (kg) percentage body fat.

Female events						Male events					
fm 50 free	time	lact	gluc	mass	%body	m 50 free	time	lact	gluc	mass	%body
Mean	26.81	10.91	5.66	62.73	15.4%		22.76	12.62	5.72	87.40	8.4%
SD	0.81	1.12	0.81	9.82	1.6%		0.33	1.63	0.63	5.20	0.9%
fm 100 free	time	lact	gluc	mass	%body	m 50 bk	time	lact	gluc	mass	%body
	61.35	11.52	6.59	58.69	17.8%		26.59	9.78	5.83	86.50	8.5%
	2.67	1.84	1.11	4.89	1.6%		1.03	1.51	0.76	6.89	0.8%
fm 100 fly	time	lact	gluc	mass	%body	m 50 fly	time	lact	gluc	mass	%body
	64.87	9.54	5.51	69.15	17.9%		26.99	9.30	5.93	79.50	10.3%
	4.79	2.48	1.13	10.82	3.0%		3.59	3.13	1.33	5.26	3.3%
fm 100 brst	time	lact	gluc	mass	%body	m50 brst	time	lact	gluc	mass	%body
	73.92	9.30	6.01	64.28	18.1%		29.01	9.65	6.15	81.33	11.33
	4.82	2.28	0.70	10.46	1.5%		0.38	0.67	0.23	2.89	2.0%
fm 100 bk	time	lact	gluc	mass	%body	m 100 free	time	lact	gluc	mass	%body
	68.53	15.85	5.83	59.50	17.8%		51.36	13.74	6.42	82.12	8.5%
	5.15	6.82	0.19	4.43	3.0%		3.37	2.96	1.31	6.55	2.5%
fm 200 bk	time	lact	gluc	mass	%body	m 100 fly	time	lact	gluc	mass	%body
	140.50	13.15	6.85	65.92	15.6%		59.00	11.95	5.89	79.00	11.5%
	6.94	1.88	1.38	6.54	2.8%		5.93	2.98	0.69	7.44	3.3%
fm 200 brst	time	lact	gluc	mass	%body	m 100 brst	time	lact	gluc	mass	%body
	167.70	10.50	6.56	66.11	17.2%		65.62	11.79	6.18	80.26	9.5%
	11.03	2.42	0.63	6.92	2.7%		3.58	2.56	0.78	3.36	2.2%
fm 200 fly	time	lact	gluc	mass	%body	m 100 bk	time	lact	gluc	mass	%body
	158.11	10.20	6.66	60.00	18.6%		63.06	11.38	6.19	79.20	11.7%
	11.12	1.81	0.55	4.27	1.6%		4.83	2.72	1.09	7.39	2.8%
fm 200 free	time	lact	gluc	mass	%body	m 200 bk	time	lact	gluc	mass	%body
	130.37	11.54	7.13	57.13	18.0%		126.63	12.27	7.00	76.00	9.3%
	6.25	1.15	0.42	6.10	1.9%		1.35	2.87	1.32	9.08	1.0%
fm 200 IM	time	lact	gluc	mass	%body	m 200 brst	time	lact	gluc	mass	%body
	146.10	11.15	6.56	60.71	17.9%		146.79	11.30	6.19	76.48	11.4%
	5.65	2.49	0.66	3.42	1.6%		21.68	2.63	0.86	5.40	2.7%
fm 400 IM	time	lact	gluc	mass	%body	m 200 fly	time	lact	gluc	mass	%body
	287.61	8.96	6.73	60.80	19.4%		129.45	11.39	6.58	77.35	10.9%
	18.22	2.35	1.24	4.21	4.1%		11.78	2.69	0.78	4.84	2.4%
fm 800 free	time	lact	gluc	mass	%body	m 200 free	time	lact	gluc	mass	%body
	542.62	8.98	6.18	57.75	12.8%		116.63	13.05	6.36	79.91	8.9%
	9.14	2.40	1.56	2.06	5.5%		7.18	2.30	0.82	4.87	1.7%
fm 1500 free	time	lact	gluc	mass	%body	m 200 IM	time	lact	gluc	mass	%body
	1045.94	3.50	8.45	63.75	14.8%		129.48	12.64	6.86	79.00	10.4%
	28.43	0.20	0.10	5.97	4.5%		6.48	2.08	1.08	12.63	3.4%
						m 400 IM	time	lact	gluc	mass	%body
							249.60	14.30	5.40	76.00	9.0%
						m 400 free	time	lact	gluc	mass	%body
							239.10	12.83	6.96	81.67	10.1%
							3.81	1.76	0.46		
						m 1500 free	time	lact	gluc	mass	%body
							961.08	6.39	7.29	76.44	10.2%
							67.43	2.50	1.14	3.71	2.2%

Table3: Mean Swimming Time, Lactate, and Glucose for Each Distance.

	Male			Female		
	Time (sec)	Lactate (mmol/l)	Glucose (mmol/l)	Time (sec)	Lactate (mmol/l)	Glucose (mmol/l)
50 Events	25.44	10.57	5.83	26.81	10.91	5.66
SD	2.34	1.79	0.10	0.81	1.12	0.81
100 events	59.76	12.21	6.17	68.70	11.55	5.98
SD	6.23	1.05	0.22	35.55	4.00	3.27
200 events	129.80	12.13	6.87	148.56	11.31	6.75
SD	10.87	0.77	0.86	14.66	1.16	0.24
400 events	244.35	13.57	6.18	287.61	8.96	6.73
SD	7.42	1.04	1.10	18.22	2.35	1.24
800 events				542.62	8.98	7.18

SD				9.14	2.40	1.56
1500 events	961.08	6.39	7.29	1045.94	3.50	8.45
SD	67.43	2.50	1.14	28.43	0.20	0.10

Glucose was lowest in butterfly, similar in breaststroke and backstroke. Freestyle had the highest glucose at 6.42 ± 1.31 mmol/l. Female 100m freestyle times were average for good class swimmers but not at a world class standard. Butterfly, backstroke, and breaststroke were also of a lower standard. Lactate was highest in backstroke and lowest in breaststroke. Glucose was highest in freestyle and lowest in butterfly. There were significant differences for male lactate between 50 and 100 swims ($p < 0.037$ conf. 95%) and glucose ($p < 0.04$). Over 200m events, men were faster in all strokes and lactate was higher in all strokes except backstroke than in the female swimmers. Females had higher glucose than males in free and breast 200m swims but lower glucose in back and IM. Both lactate and glucose were not significantly different between 100m and 200m events at $p = 0.05$ (95% confidence level), where-as in females, although lactate was not significantly different ($p = 0.4$) glucose was different ($p = 0.007$).

Female mean 400m free (270.56 ± 11.89 sec) and 800m (542.62 ± 9.14 sec) had similar lactate (8.96 ± 2.35 vs 8.98 ± 2.40 mmol/l respectively) and glucose (6.73 ± 1.24 vs 6.18 ± 1.56 mmol/l respectively). Female 1500m free had significantly lower lactate (3.5 ± 0.2 mmol/l) than 800m free ($p = 0.001$) and significantly higher glucose (8.45 ± 0.10 mmol/l) than 400m and 800m free ($p = 0.01$ & 0.003 respectively). Male 400m free and 1500m free lactate was significantly different $p = 0.001$ from each other, whereas glucose was not significantly different (6.96 ± 0.46 vs 7.29 ± 1.14 mmol/l). Mean differences in aerobic, glycolytic, and anaerobic contributions are shown in Table 3. Strokes were combined to allow for comparisons between responses to various event lengths. 50m & 100m distances were only significantly different in their glycolytic contribution (Aerobic $p < 0.36$, Glycolytic $p < 0.00$,

Table 4: MAssessment of Contribution over Each Distance.

	Male			Female		
	Aerobic %	Gylcolytic %	Anaerobic %	Aerobic %	Gylcolytic %	Anaerobic %
50 Events	32.45	16.51	51.04	41.71	13.14	45.15
SD	6.03	2.07	8.05			
100 events	32.38	23.38	44.24	42.69	19.65	37.65
SD	8.08	4.40	4.59	15.22	9.11	11.27
200 events	26.88	33.75	39.37	30.20	34.98	34.83
SD	11.38	9.79	3.79	8.67	4.83	5.14
400 events	19.76	39.20	41.04	43.55	34.60	21.85
SD	26.40	26.16	6.51	27.23	19.76	10.50
800 events				55.30	23.50	21.20
SD				28.85	31.13	11.40
1500 events	67.12	30.16	2.72	18.73	50.89	30.37
SD	21.31	20.27	12.77	4.54	1.79	2.75

and Anaerobic $p < 0.52$.) The differences between 100m and 200m events were similarly non-significant in aerobic & anaerobic contribution ($p = 0.11$ and 0.08 respectively) but significantly different in glycolytic contribution ($p = 0.04$) (significance at 95% confidence level).

When freestyle was considered separately, significant differences were seen between event duration. This is shown in figure 1.50m free had a larger anaerobic contribution than in 100m freestyle and a smaller glycolytic response. 100m freestyle had a significantly larger anaerobic contribution than 200 freestyle, and 1500m free had a larger aerobic contribution (67.12 vs 45.89%) and smaller anaerobic contribution (2.72 vs 46.11%) than 400m free. Women had a significantly larger glycolytic response in the 100 free than in the 50m free and a significantly larger anaerobic contribution in the 200m free than the 400m free (Table 4). In contrast to the men, the women had a smaller aerobic contribution in the 1500m free than the 400m but showed a far greater reliance upon glycolytic metabolism in the longer event. All significance levels for freestyle events are shown in Table 5 and Figure 1. Comparison between Olympians and other finalists. Separately we looked at the profiles of swimmers who qualified to swim at the Olympics in 100m and 200m freestyle. These were compared to the finalist who did not qualify in the same events. The profiles with the relative contributions are shown in Figure 2. Marked differences appear between the Olympic qualifiers and those swimmers who did not qualify. When the Olympic qualifiers profiles were compared to the modeled values for efforts at their achieved swim times, there were clearly similarities both for the 100m swimmers and the 200m swimmers (Figure 3).

Table 5: P Values for Males & Female, Differences between Freestyle Events Metabolic Contributions.

Male			
dist vs dist	Aerobic %	Glycolytic %	Anaerobic %
50 - 100	0.07	0.0002	0.002
100 - 200	0.06	0.14	0.0002
200 - 400	0.21	0.13	0.11
400 - 1500	0.002	0.08	0.001

Female			
dist vs dist	Aerobic %	Glycolytic %	Anaerobic %
50 - 100	0.1	0.01	0.12
100 - 200	0.09	0.07	0.48
200 - 400	0.06	0.21	0.002
400 - 800	0.19	0.2	0.41
400 - 1500	0.03	0.08	0.06
800 - 1500	0.06	0.09	0.12

Discussion

Having previously modeled contributions during maximal exercise [12] and expanded the basis of how aerobic metabolism was explained in this high intensity environment, our goal was to identify the contribution of metabolic pathways during competition swimming. What was noticeable in the present study was that for males the anaerobic contributions in the 100m (48 sec to 54 sec), 200m (107 sec to 116 sec) and 400m (230 to 245 sec) were very similar for these sample groups suggesting that differences in performance must be due to the balance of aerobic and glycolytic contributions. Similarly, in females the anaerobic contribution was similar in 100m 200m and 1500m events (which in itself is surprising) and lower in 400m and 800m events. Previous authors have focused on showing that the aerobic system played a larger role in the overall contribution to exercise metabolism at maximal efforts over time lines from 22 seconds to 8-10 minutes [8,9] and that the aerobic contribution exceeded that of the anaerobic contribution within 30 to 120 seconds.

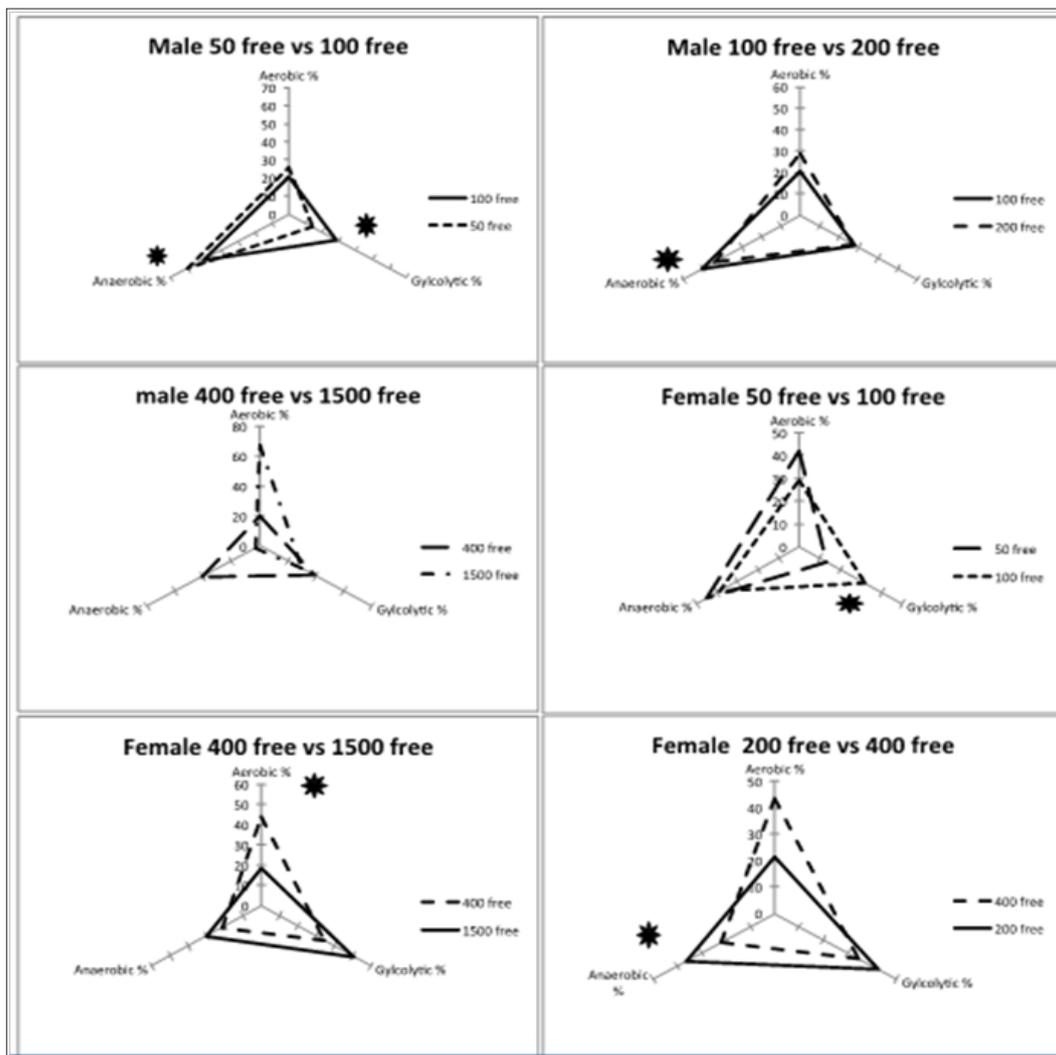


Figure 1: Profiles of Freestyle Events Where Significant Differences Occurred In Metabolic Mechanisms.

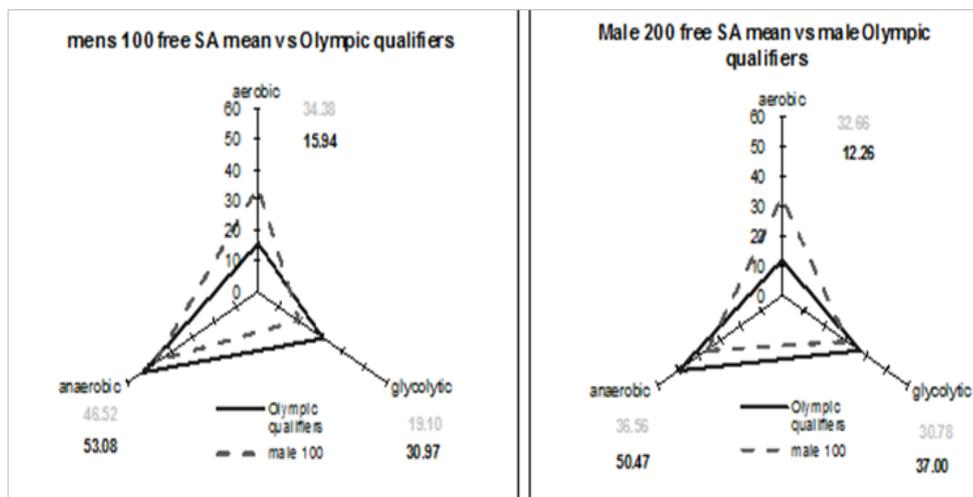


Figure 2: Profile Of Olympic Qualifiers Vs Mean Finalists.

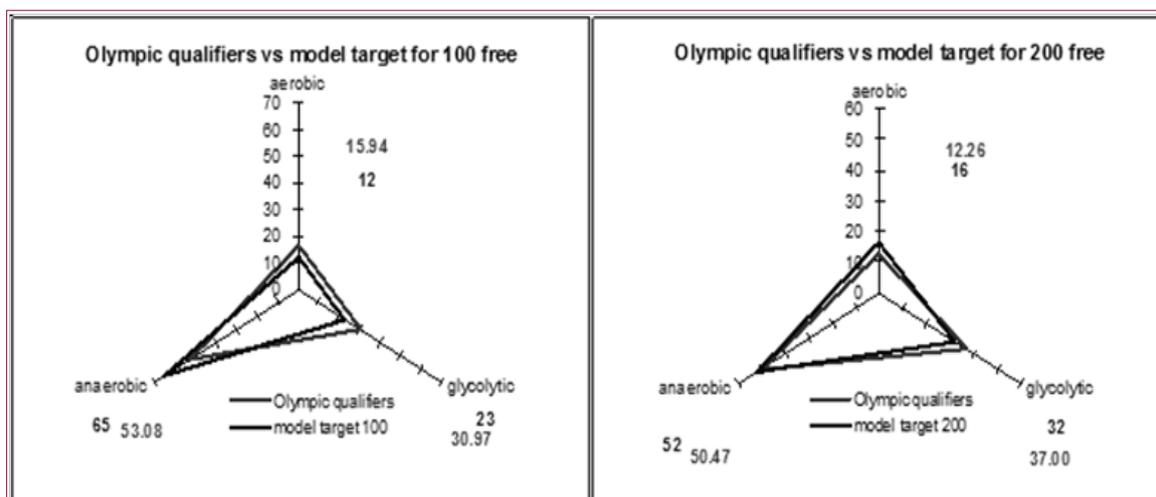


Figure 3: Model Profiles for 100 And 200 Freestyle Vs Olympic Qualifiers.

Where the present findings do differ, is that we see the definition of aerobic and aerobic glycolytic pathways to be of importance to truly understand how the energy demand is being met. It is this separation of the two aerobic mechanisms that may lead to better clarification in training methodology. Indeed, we feel that it is in this matter that major assumptions have overlooked the relative intensity of aerobic glycolytic work. Contribution of aerobic and anaerobic mechanisms have previously been identified in simulated race conditions either in the lab during treadmill running [10,11,14] cycling [5] or in running on the track [15]. Where the present research is different is that the subjects were tested in real time competition situations. Broadly, our results were in agreement with [4,16,17], in that the 200m swimming time line is approximately the same as that for 800m running in males and females, and the anaerobic contributions observed in swimming (Male 39.37% vs 39.7%; female 34.83% vs 29.9% (present study & Duffield and Dawson data), are similar to the findings of Spencer and [8] (34.%).

Additionally, when compared to 100 and 400m events as studies by Rodriguez and Mader (2003) and Laffite (2004) the basic split of anaerobic contribution in swimming events was also similar. As event time increases from 1 minute through to 8 minutes, glycolytic contribution will increase while aerobic contribution will only increase at a slower rate [12]. Anaerobic contribution should fall to a minimal rate by 15 minutes [12,8]. Male swimmers demonstrated a growth in glycolytic function from the 16.51% in the 50m events and grew to 39.2% in the 400m. Within the 1500m free, the relative glycolytic contribution had reduced to 30.2%. This is contrary to what we have found previously with this time course of event (16-18 mins). Aerobic contribution reduced from 32.4% in the 100m events to 26.4% in 400m events, but was at a high point in the 1500m (67.1%). Female swimmers in this study demonstrated mostly stable aerobic and glycolytic contributions over the events from 50m to 800m with large changes only occurring in the 1500m freestyle.

This lack of ability to change contribution across different event distances would suggest that there is some form of stagnation in training and performance development. It may also symbolize that exercise economy is not at its optimal, a factor that is important for success [18]. The comparison of the profiles of the Olympic qualifiers (and later medal winners) revealed that their profile of 3 ways contribution matched very closely to the predicted model. This raised a number of questions regarding what is being seen in the profiles of swimmers who do not qualify for the high performance events. The time line used in the model fitted all events from 50m to 1500m and beyond. Why were so many swimmers who were tested not showing the same profile as those who made the Olympics? Performance improvement is a function of the season training intensity [19] and the balance of overload and recovery, particularly during the final 6 weeks leading into major competition [19].

If the season does not have sufficient intensity, or for that matter, a full range in higher intensities then performance is likely to plateau. Additionally, the amount of detraining that takes place that influences the starting point of the following season also reduces the level of improvement that can be achieved even if there is good adaptation to in-season training [19]. Best results are characterized particularly by high training loads during pre taper periods followed by sharp decreases of load during taper, although both periods require initial increased loading followed by appropriate decreased loading [19]. The lack of anaerobic development seen particularly in female swimmers in this sample group may indeed be due to such situational conditions not being correctly achieved. For the male swimmers, however, glycolytic development appears to be lacking. This would suggest that males tend to train either at high intensity or at low intensity, but do not cover the middle intensities that give them sustained aerobic power [20]. An inability to produce sufficient sustainability at higher intensities involved with swimming racing would then be affected as estimates of the anaerobic swimming capacity are influenced by variations in both anaerobic and aerobic energy release [21].

As the anaerobic swimming capacity does not provide a reliable estimate of the anaerobic capacity either, the balance of how the aerobic metabolism is split between purely aerobic and glycolytic may hold more power in performance variability than realised. Other influences on the performance outcome may also be balance of stroke indices. Although we did not include this data in this study, there were large differences in stroke rate and stroke length between swimmers in all events and previously this has been shown to affect performance [22]. There is an optimum ratio between stroke rate and stroke length for best performance. It would be interesting to see how swimmers, who do not achieve the target performance, and the target profile in this current method, also relate to performance in stroke rate stroke length ratio. Certainly both s and Hellard et al. [22] have discussed the need for personalization of training programs for each individual swimmer.

The development of performance and the rate at which this adaptation occurs is variable [23] and appears to depend on the volume, intensity and frequency of the training [24]. This may also

require that younger swimmers are trained to the requirements that best match the abilities of their developmental stage as well as the requirements of the events they are targeting as the effects of competition on younger swimmers have been seen to create a negative change in training state [25]. The model used in this paper has presented values of aerobic, glycolytic and anaerobic contributions in swimming events at national championships. The tri-phasic model offers greater opportunity to have insight of an athlete's preparedness for competition and achieving the performance outcome that is targeted. The addition of the glycolytic pathway allows better understanding of why and how performance is achieved or fails during competition. Much of the error in balance appears to come from training that does not match the requirement of the targeted effect. Swimmers who qualify for Olympics appear to need to match the model requirements very closely. To do this relies on training balance, skill development, and stroke indices ratios [26-28].

Conclusion

This study showed that to reach the highest level of performance, specific and accurate identification of aerobic pathways that are split into 2 distinct areas, Aerobic oxidative and Aerobic Glycolytic [29-31]. By using the tri-phasic model (the third component being anaerobic pathways) gives greater understanding of how and why a performance may be achieved. To maintain performance through a race requires a swimmer to be able to excel at maintaining the characteristics of performance (stroke length stroke rate, balance and muscle control), that can only be achieved if the pathways of energy delivery are finely tuned to meet the demand. This new model offers greater insights and allows for better estimations of relative contribution patterns. It also suggests that the contribution of energy systems currently suggested may need revising.

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