

World race walking research

[Monograph]

Martin Pupiř et al.

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INTRODUCTION

The Matej Bel university is one of the biggest universities in Slovakia with great sports tradition. Since the publication is to deal with walking let me mention some our graduates and students:

- Jozef Pribilinec – Olympic champion in 20 km race walking (1988)
- Pavol Blazek – European champion and the world record holder in 20 km
- Roman Mrazek – indoor championships medal holder, two times the 5th in Olympics

as well as the others: Juraj Bencik, Peter Korcok, Milos Batovsky, Martin Pupis, Michal Blazek, Matej Spisiak, Igor Kollar, Roman Bencik, Robert Valicek, Erik Kalina, Peter Barto, Peter Seben, Zuzana Malikova, Zuzana Blazekova, Maria Galikova, Maria Czakova, Ivan Brozmanova, Miroslav Dumbala, Barbora Strnadova, Zdeno Babik, Ondrej Kocur, Martin Skarba, Kazimir Verkin, Vladimir Savanovic (Serbia). Except walkers many other prominent sportsmen studied and study at our department. Let me mention Elena Kaliska (water slalom Olympic champion), Pavol Hurajt (3rd place in Biathlon on Winter olympic games 2010), Martina Hrasnova (3rd place on World athletics championship in Berlin 2009), Lubos Krizko (European record holder in swimming), Michal Handzus (NHL hockey player), Alena Prochazkova (World cup winner in cross-country skiing), Klaudio Farmadin (World championship in karate silver medal) and others.

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THE INTENSITY OF RACE WALKER LOAD AT VARIOUS PERFORMANCES AT 20 AND 50 KM

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Abstract

The research compares the different 20 km (and 50 km) races for the world's leading walker. The research shown, that it is very important that the racer at least the first five minutes of the pulse rate does not exceed 95% ANT at 20 km race and just 95% of ANT in the race for 50 km. For the perspective of object of research is essential that the intensity of the load for the first 5 km race at 20 km does not exceed the average levels of ANT. The 50 km race showed that for him is corresponding intensity for the first 10 km approximately 90% ANT.

Key words: heart rate, race walker, performance

Problem

According to Dvořák et al. (1990) is a race walking the specific discipline of endurance character where the racer normally complete 98% of track in an aerobic mode. Of course, it is difficult to express objectively the percentage share of each energy system to load. To define objectively the load intensity in endurance performance are showed as objective indicators anaerobic threshold (ANT) and maximal oxygen uptake ($VO_2\text{max}$). ANT and $VO_2\text{max}$ are therefore now seen in endurance sports as the most objective indicators of training and ultimately race loads. Sports training and development of endurance have become the center of many authors, among others Hagberg and Coyle (1983), Hamar (1989), Choutka - Dovalil (1991), Noakes (1991), and Truksa Kucera (2000), Chin et al. (2001), Power (2002), Broďáni (2002), Čillík - Korčok (2003), Baker - Horton (2003), Bill et al. (2003), Broďáni - Vavák - Selinger (2003), Čillík (2004), Korčok - Pupiš (2006), sumpter - Soulek - Kucera (2006), Dry (2007), Dry et al. (2008), Kisiel (2009) etc. Bielik et al. (2006) regarded ANT as one of the most significant variables with regard to prediction of performance in endurance sports. In endurance sports equally important parameter is $VO_2\text{max}$, maximum amount of oxygen that the lungs are able to extract from the tidal air and that blood transports to working muscles (Hajkova, 1997). The intensity of walker load at 50 km takes about 93-97% of

anaerobic threshold and in the 20 km race is up at 104% ANT (Pupiš - Čillík, 2005). Dependence between ANT and VO_2max in the leading walkers was found to Pupiš and Broďáni (2007), 80-100%, the oxygen generated by the ANT approximately 80 to 100% of the maximum level of VO_2max . Due to the fact that the 20 km race walkss almost an hour and a half, and 50 km races walk about four hours, the intensity is very high, which is reflected also in the body of walkers after the race by the negative, subjective feelings (corresponding state of fatigue) and also that in the body is possible to monitor objectively the changes in chemical composition and related physiological processes, such as increase in resting heart rate or body temperature change. It is also essential to take into account the subjective feelings of athletes, where it appears that the consequences of exhaustion should be removed by long enough resting, in which all the necessary functions gradually normalize. After the end of loading the body must recover, if it must work again (Štulrajter - Brozmanová, 1990) and, therefore, re-training process begins only after the full recovery (Glesk, 2005).

Aim of work

1st aim of the work is to compare the different 20 km races for the world's leading walker.

2nd aim of the work is to compare the different 50 km races for the world's leading walker. Mutually we compare the races in which the athlete made M.T. personal record with the most important races of the season.

Methodology

Characteristics of subjects: M.T.

Age of racer at the time of research: 26-27 years

Body weight: 75 kg

Body height: 185 cm

$\text{VO}_2\text{max.kg}^{-1}$: 73,3 $\text{ml.kg}^{-1}.\text{min}^{-1}$

VO_2max : 5454 ml

Oxygen pulse: 28,5 ml

Subcutaneous fat: 7,4%

Anaerobic threshold 178 bpm

hematocrit - 48.6%

haemoglobin - 164

club - VŠC Dukla BB

Personal Bests:

3 km: 11:17,35

5 km: 18:57,4

10 km: 39:41

20 km: 1:20:53

50 km: 3:41:32

The most significant achievements:

2010 - World Cup winner in walking the 50 km

2009 – 9th place at 20 km and 10th place at 50 km World Championship2006 - 6th place at European Championships

For all take-offs, we monitored the course of his heart rate during loading. The course of heart rate was monitored by using a load tester Polar RS 800. Overall, we compared three 50 km races and four 20 km races. Both tracks were to compare the races in which the pursued athlete made a personal record with the most important race of the season.

50 km Race:

28/03/2009 - Meeting EAA Dudince - 3:41:32 (personal best)

22/08/2009 - World Championship 2009 Berlin (Ger.) - 50 km 3:48:35 (10th place)

15/05/2010 - World Cup 2010 Chihuahua (Mex.) - 3:53:30 50 km (Winner)

20 km Race:

25/04/2009 - Meeting EAA Podebrady - 1:20:53 (personal best)

24/05/2009, European Cup 2009 - Metz (Fra.) 1:27:29 (9th place)15/08/2009 World Championship-2009 Berlin (Ger.) - 20 km 1:21:13 (9th place)27/07/2010 European championship in 2010, Barcelona (Esp.) - 20 km 1:22:20 (7th place)**Results**

Our previous studies (Pupiš - Čillík, 2005; Pupiš - Savanovič - Štihec, 2009) show that heart rate was racing at 50 km walkers on the range of 93-97% ANT. Figure 1 depicts the course of heart rate in M.T. the Slovak Record in walking the 50 km in Dudince (28/03/2009), where he earned a time of 3:41:32 hours and as shown in Figure 1, M.T. Record began racing at the

SR pulse rate slightly above 160 bpm, and in the end exceeded 185 bpm. The average heart rate was substantially revised upwards depending mainly on the increasing pace. The average value of heart rate reached 172 bpm, which corresponded to 96% on ANT. Of course, the increase in heart rate was not related solely to increase of the pace, but also with increasing fatigue. Symptoms onset of fatigue and thus increase of the heart rate independent from the pace was displayed especially during the last 20 km. Penultimate ten kilometres long section is completed at the time of 43:01 minutes at an average pulse rate 178 bpm, but the last ten kilometres completed on 43 seconds slower, but the pulse rate was 182 bpm

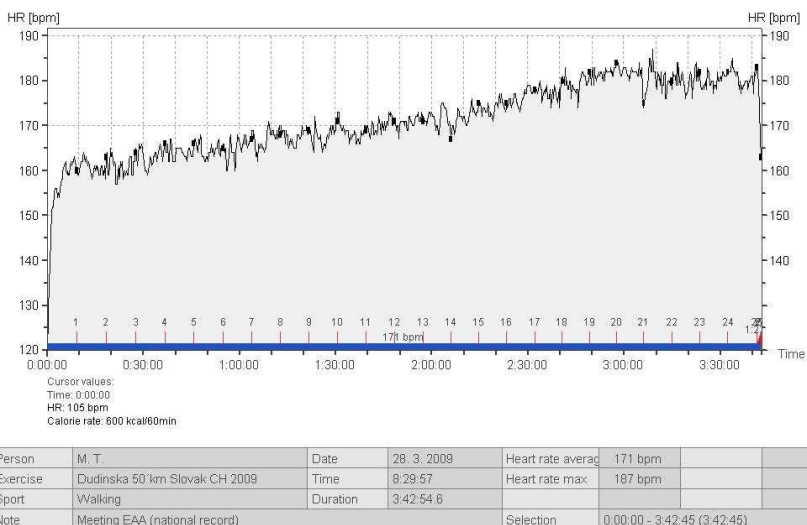


Fig. 1 Course of heart rate M.T. on the 50 km race in Slovak Record at a meeting of EAA in Dudince, 2009

Physiological load curve shows that in the National Record elected on the first 30 km the optimal rate well below of ANT. The level of ANT approached about 30th km, both the last two ten kilometres sections completed on average above the ANT. Step intensity of the load brings him

in his premiere on 50 km a national record and performance of classifying it in the absolute world leaders in this track.

Another course had the load of WCH in 2009 in Berlin, where M.T. conquered in 50 km race walking the tenth place. As shown in Figure 2 the pulse frequency is already beginning to move a lot above 170 bpm and that is lately showed as unduly rapid rate leading to the fact that M.T. slowed markedly on the last 20 km. While the first three ten kilometres sections are completed in time 44:44 min 44:10 min 44:40 min, then the fourth ten kilometres section is completed in 46:33 min and 48:28 minute for the final, while heart rate still exceeds the value of bpm. The top events are characterized by the fact that racer must adapt to the tactics of his rivals and this happened in this case. However, accompaniment was that the heart rate M.T. already at the sixth kilometre exceeding the value of ANT (Figure 2).

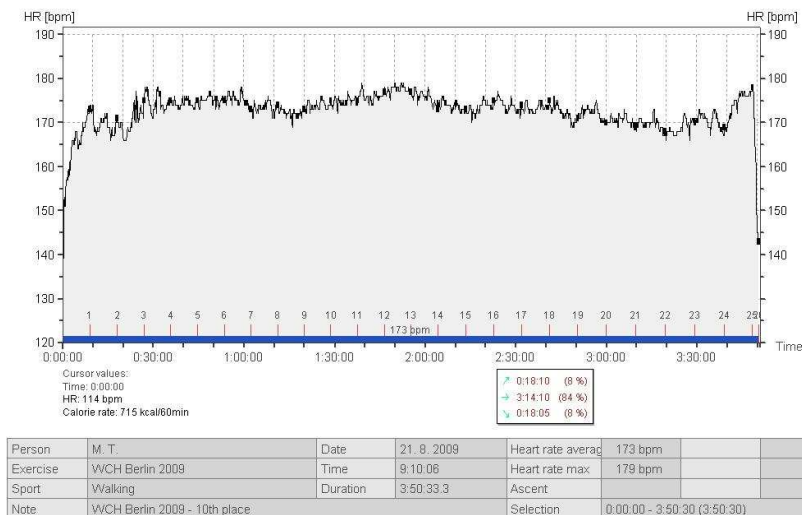
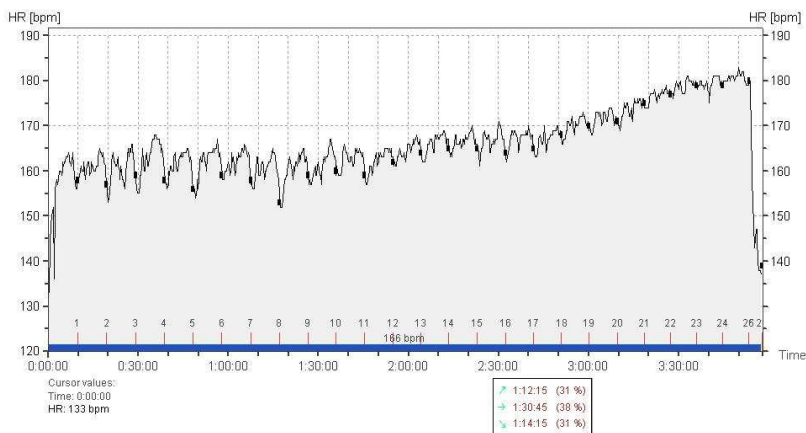


Fig. 2 Course of heart rate of M.T. on the 50 km race at the world championship in 2009 in Berlin (10th place)

The significant decrease in heart rate after 30 km was due to a decrease of speed, which led to the M.T. thinking to abort the competition. M.T. the

race eventually finished, but "slightly" frustrated from improper tactics which deprived him of a better result.

The victory at the World Cup chose M.T. again (as in the National Record in 2009) rate of less effort when his maximum heart rate ranged up to half of the race below 168 bpm, and average heart rate below 164 bpm. This fact was related in part from the fact that the race took place at a higher altitude at high temperatures. However, M.T. was sufficiently acclimatised and adapted (as the race was preceded by a month-long training in the Mexican mountains) and so he was able to accelerate at the second half of the race and win the most important race walking 2010th.



Person	M. T.	Date	15. 5. 2010	Heart rate averag	166 bpm		
Exercise	World cup 2010	Time	7:59:02	Heart rate max	183 bpm		
Sport	Walking	Duration	3:57:44.9	Ascent	265		
Note	World cup 2010 - Winner	Selection	0:00:00 - 3:57:30 (3:57:30)				

Fig. 3 Course of heart rate of M.T. at the 50 km race at the World Cup 2010 in Chihuahua (1st place)

As it is shown in Figure 3, M.T. was close to the limit of ANT around the 38th km thanks to the "saved up" forces he managed to overcome in the last ten kilometres below the 44th min, and due to this acceleration he was able to overcome opponents who did not adjust their rate of high-altitude, ambient temperature and possibly even their current fitness. M.T. has

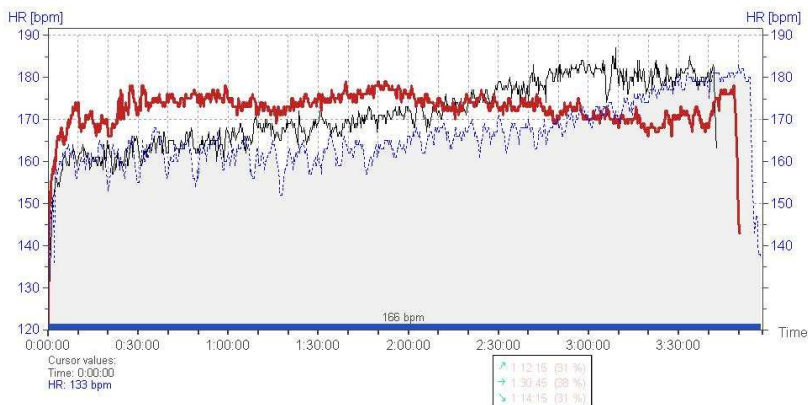
become after Jozef Pribilinec only the second Slovak, who managed to win the World Cup in walking and the first ever Slovak winner at 50 km.

Table 1 Comparison of heart rate for each race at 50 km

	Dudince	Berlin	Chihuahua
Finish time*	3:41:32	3:48:35	3:53:30
Minimal HR (bpm)	105	114	133
Average HR (bpm)	171	172	168
Maximal HR (bpm)	187	181	183
Number of heart beats during 50 km	38133	39660	39466
Recovery - 60 seconds after finish (bpm)	15	15	22

* The table shows the official time (total duration of the images is the recovery)

If we compare the summary of the load of M.T. in these three races, we find out the clear conclusion that for the racer the rate has been too fast at the beginning of World Championship racing. Looking at Figure 4 we see clearly that the heart rate curve in the victory at the World Cup and the Record of the SR tended to increase, contrary to the WCH where was more downward trend.



No	Exercise	Date	Cursor HR	Heart rate	Duration	Note
1.	Dudinska 50 km Slovak CH 2009	28. 3. 2009	105	171 / 187	3:42:54.6	Meeting EAA (national record)
2.	WCH Berlin 2009	21. 8. 2009	114	173 / 179	3:50:33.3	WCH Berlin 2009 - 10th place
3.	World cup 2010	15. 5. 2010	133	166 / 183	3:57:44.9	World cup 2010 - Winner

Fig. 4 Comparison of heart rate course M.T. at the 50 km race at the National Record, on World Championship 2009 and World Cup victories

In terms of energy intensity was both races in the 2009, similar, and also the average heart rate varied less, but the final effect was different. M.T. in the first race escalated considerably greater rate and felt no crisis. By contrast, on the WCH has slowed significantly and the race has reached at the brink of physical strength, even thought about completing the race. This fact could be partly influenced by the fact that WCH has completed two-start and 50 km race followed for 6 day after the 20 km race. The course at World Cup victory was similar to the National Record in 2009. As we can see in Figure 4 and Table 2 at the World Cup as well as in the Record of the SR at the start of the race ranged racing heart rate at 160 bpm, what is the value below 90% of ANT, while on the WCH it was about 95% ANT. Based on this experience, we assume that for the M.T. is appropriate that to the half of the race he should not exceed the intensity corresponding to 90% ANT.

Table 2 Course of the various races at 50 km from the perspective of HR

		0-10 km	10-20 km	20-30 km	30-40 km	40 – 50 km
Dudince	Average HR	160	166	171	178	182
	Max. HR	167	173	176	184	187
	Time	45:54	44:48	44:04	43:00	43:43
Berlin	Average HR	170	174	176	173	171
	Max. HR	181	178	179	177	178
	Time	44:44	44:09	44:40	46:33	48:27
Chihuahua	Average HR	160	161	164	169	178
	Max. HR	168	167	170	174	183
	Time	48:18	47:42	46:53	46:39	43:56

In terms of race load and thus response of the organism of race at 20 km all four performances were very similar, but on the European Championship

the average heart rate was 180 bpm, in the personal record the average heart rate was 182 bpm, in the European Cup it was 183 bpm and in the World Championship race it was 185 bpm. For the race at 20 km is characteristic that there are minor variations in rate, which stems from the fact that a race walker passes at a higher intensity than 100% ANT. As we can see in Figure 5, the personal record heart rate ranged from second kilometre until the eighteenth kilometre in a very narrow diapason of about $182 \text{ bpm} \pm 4 \text{ bpm}$. Of course, lower heart rate at the beginning linked to the incorporation, until the end there was a rise in heart rate, which was caused by increasing rate of speed at the end. The average rate during the race was at 4:03 min, but the final kilometre ran in 3:54 minutes. Heart rate in the last kilometre average level of 188 bpm and the maximum amounted to 192 bpm.

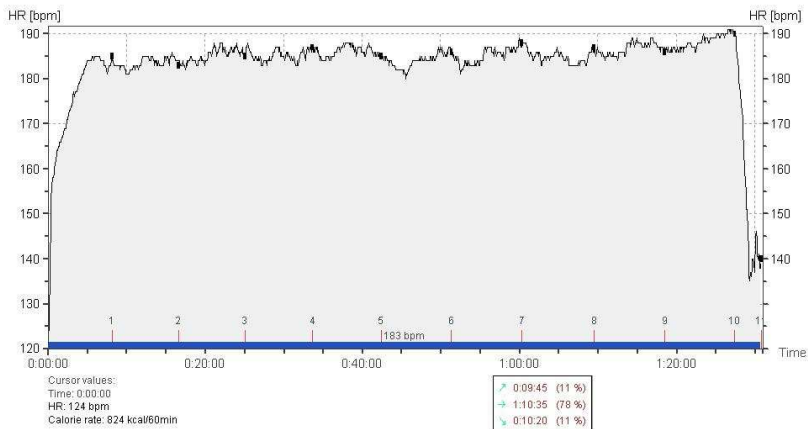


Person	M. T.	Date	25. 4. 2009	Heart rate average	182 bpm		
Exercise	Podebrady EAA	Time	15:01:15	Heart rate max	191 bpm		
Sport	Walking	Duration	1:22:05.5	Ascent			
Note	Podebrady EAA meeting (PB)			Selection	0:00:00 - 1:22:05 (1:22:05)		

Fig. 5 Course of heart rate M.T. at the 20 km race in a personal record in the EAA meeting in Podebrady

European Cup 20 km were significantly affected by high ambient temperature. M.T. completed the first 2 km in 8:10 min and heart rate

before the first kilometres exceeded 185 bpm. Then the rate slowed to 10 seconds per kilometre and also a levelling off (or to decrease) heart rate. After the tenth kilometre was up to the situation that M.T. walk individual kilometres at a rate of around 4:30 min, a slower rate than the rate at which it is able to complete 50 km. While we see (Figure 5) that the personal Record had a heart rate of M.T. through the race slightly upward trend, in the European Cup there was a impact fall and increased heart rate. In the last kilometre reached the heart rate value 191 bpm (more on Figure 6) at a rate of 4:24 per kilometre, which was up by almost 20 seconds slower rate than at the beginning. In this race was remarkable the significant difficulty of environmental temperature, when all racers have similar problems and significantly lagged behind their personal maximum.

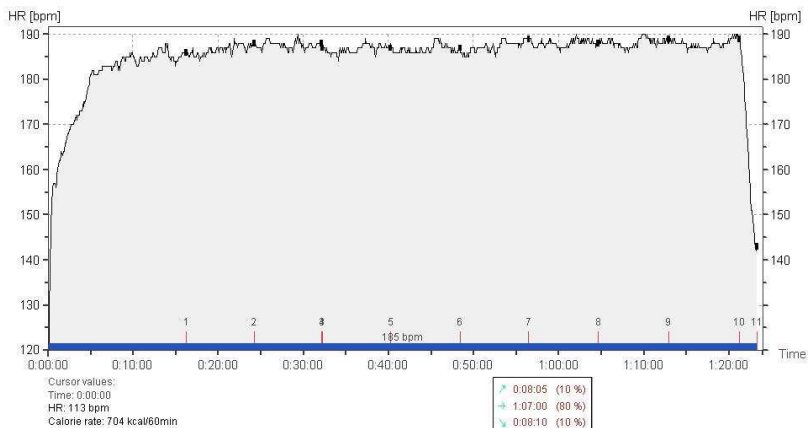


Person	M. T.	Date	24. 5. 2009	Heart rate averag	183 bpm		
Exercise	European cup 2009	Time	15:28:58	Heart rate max	191 bpm		
Sport	Walking	Duration	1:30:49.7	Ascent	35		
Note	7 th place			Selection	0:00:00 - 1:30:45 (1:30:45)		

Fig. 6 The course of heart rate M.T. at the 20 km race at the European Cup in 2009

At the 20 km race in the world championship in Berlin M.T. adapted to the rate at which the group marched. Due to the rate at the level 3:58 min after the fifth kilometre there was a significant increase of heart rate to 186 bpm \pm 4 bpm. In the second half of the race, the decrease of rate was more than

10 seconds per kilometre, while heart rate did not decrease, even in some sectors have seen their growth, which was probably due to acute exhaustion and acidity of internal environment of the organism. Even though the racer must accelerate at the begining of race, he achieves good result and performance.

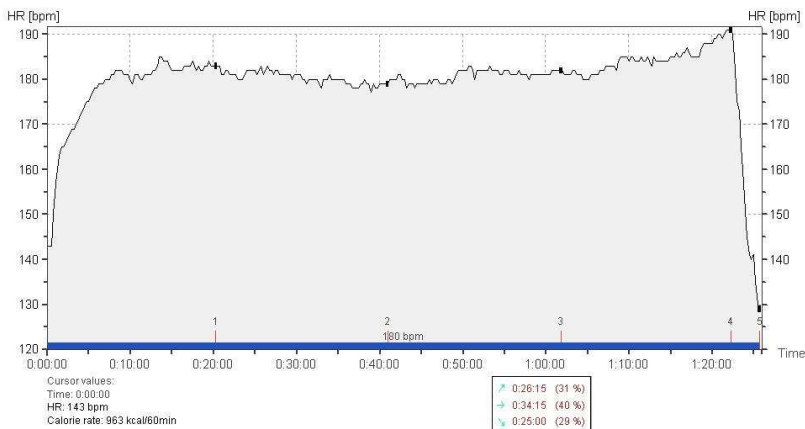


Person	M. T.	Date	15. 8. 2009	Heart rate averag	185 bpm		
Exercise	WCH Berlin 2009	Time	13:00:14	Heart rate max	190 bpm		
Sport	Walking	Duration	1:23:22.5	Ascent	5		
Note	9th place	Selection	0:00:00 - 1:23:20 (1:23:20)				

Fig. 7 Course of heart rate M.T. at the 20 km race the world championship in 2009 in Berlin

Overall, however, these events can be viewed as both physiologically and tactically controlled, since the racer didn't lag significantly after his personal record and what is more he finished at ninth place, which was moderately above expectation. As seen also in Figure 7, the average heart rate in the race reached 185 bpm, which corresponds in his case to about 104% ANT, but from the fifth kilometre, the average ranged between 188 to 189 bpm, which is on the level 106% ANT. From the fifth kilometre there are not any significant differences in heart rate, but despite this fact, the rate decreased at the end of the race to the level of 10 seconds.

European Championships in Barcelona started M.T. in additional discipline (20 km). Analyzed from all competitions at 20 km, the average heart rate for this race achieved the lowest level (only 180 bpm = 101% ANT). In Figure 8 we can see that after an initial increase in heart rate (the fourth kilometre) to over 185 bpm occurred in the middle of the race a decrease in heart rate below the level of ANT.



Person	M. T.	Date	27. 7. 2010	Heart rate average	180 bpm		
Exercise	ECH 2010	Time	8:04:52	Heart rate max	191 bpm		
Sport	Walking	Duration	1:25:47.6	Ascent	310		
Note	7th place			Selection	0:00:00 - 1:25:45 (1:25:45)		

Fig. 8 Course of heart rate M.T. at the 20 km race at European Championships 2009 in Barcelona

This decrease was mainly due to the slowdown in the rate of the race in the middle. M.T. in this part of the race wasn't in any part of the group and he ran alone. In this section, he fell (down) in the overall ranking. However, we can see also in Figure 8 in the end of the race there was a significant increase in heart rate, which caused a significant acceleration. At the end of the race he moved away from group and at the last kilometre he attacked the leading group of athletes. He finished the race at the seventh place, but with the same time as the racer on the 6th place.

Table 3 shows that the heart rate reached highs in all four competitions with only 1 bpm of difference, while at the average heart rate this difference came to 5 bpm. From the perspective of the overall load World Championship in Berlin can be seen as the most intense race, where was the highest average heart rate.

Table 3 Course of the heart rate for each race at the 50 km

	Podebrady	Metz	Berlín	Barcelona
Finish time*	1:20:53	1:27:29	1:21:13	1:22:20
Minimal HR (bpm)	122	124	113	129
Average HR (bpm)	182	183	185	180
Maximal HR (bpm)	191	191	190	191
Number of heart beats during 50 km	14639	16222	15032	15080
Recovery - 60 seconds after finish (bpm)	17	19	21	18

* The table shows the official time (the duration of the images is with a pick)

Of course the intensity of heart rate does not depend on the rate, but also on ambient temperature, the current state, the intensity of warm-up and the rate at the beginning of the race. In terms of total energy consumption was the most challenging race course in the European Cup as a permanent load was at 5-6 minutes longer than in other three performances, which means a summary difference of 1000 bpm.

Comparing all four competitions at the 20 km from the perspective of physiological curves, so when looking at Figure 9, we can see that the World Championship 2009 was in the first half of the race average heart rate slightly higher. This arises also from the fact that the racer had to adapt the tempo of the group of racers and in his personal record he was dictating the rate through the race itself. Similarly, higher heart rate was also in the race of the European Cup in 2009 where we see a similar growth trend in heart rate at the beginning of the race. From the personal record as well as the result from European Championships, we see that the increase in heart rate was slower at the beginning, but in Figure 9, we see an obvious decrease in heart rate in the middle of the race on the European Championships. However, in both of these competitions in the end he

managed to step up the rate and thus achieve an average growth, as well as the maximum heart rate.

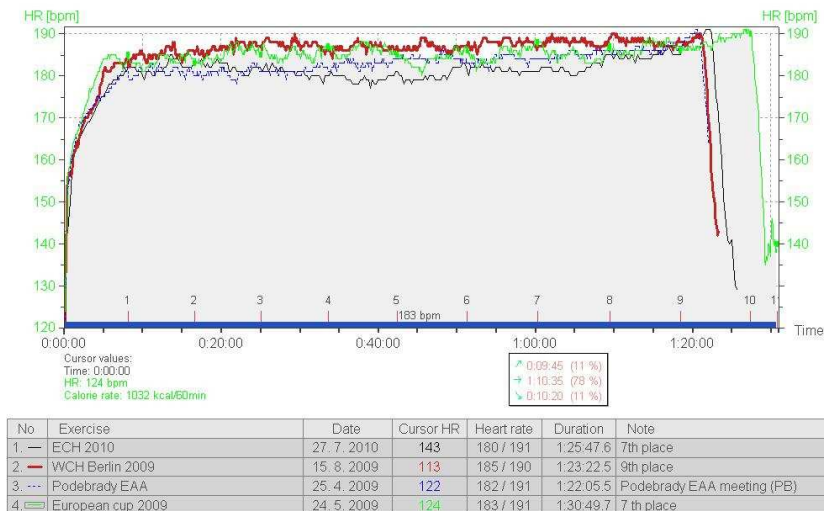


Fig. 9 Comparison of heart rate course M.T. at the 20 km race in a personal record, in the European Cup, in 2009 World Championship and European Championship 2010

In Table 4 we can see that the pulse frequency was on average highest in the race at the World Championship in Berlin, and therefore the body has been subjected to loads of greater intensity. At the 20 km race, the race is usually less temporized and every racer must be (especially for championships) adapted to the rate of rivals, as it was the case with M.T. on World Championships and European Championships. While on the world championship in 2009 the rate at the beginning of the race was slightly faster than would be needed, both tactically on European Championships in 2010 (after the acceleration in the rate of the front group) slowed. In races where the racer selects at the beginning faster rate, it is likely that walker will have an oxygen deficiency, which the racer perfectly balanced and the race was finished without a sharp slowdown. As shown in Figure 9, the racer made in all competitions at 20 km after about 6 min value of the ANT,

while in the first 4 min (ie the first km) varied the pulse rate at 95% of the ANT. According to the trend of events it appears in M.T. how convenient for him is to start the race slowly and gradually accelerate the rate. Therefore M.T. is probably more successful at a 50 km, although its results can be classified among the world's leading walkers at 20 km.

Table 4 Course of the various races, at 20 km from the perspective of HR

		0-5 km	5-10 km	10-15 km	15-20 km
Podebrady	Average HR	177	182	184	186
	Max. HR	183	184	186	191
	Time	20:12	20:22	20:12	20:06
Metz	Average HR	180	185	186	187
	Max. HR	188	188	189	191
	Time	20:53	21:33	22:32	22:28
Berlín	Average HR	181	188	187	188
	Max. HR	186	190	189	190
	Time	20:15	20:03	20:18	20:39
Barcelona	Average HR	177	180	180	184
	Max. HR	185	182	183	191
	Time	20:20	20:39	20:51	20:27

In the Table 4 we can clearly see that the personal record (at the EAA meeting in Podebrady), was the trend of growth in average heart rate during progressive races (like the European Championships in Barcelona 2010). In the European Cup as well as in the world championship already in the

second five kilometre section heart rate exceeded 104% ANT, which is also shown by our previous studies (Pupiš - Čillík, 2005; Pupiš - Savanovič - Štihec, 2009) as an excessively high load of intensity.

Conclusion

Based on our findings, we recommend that walkers start the race at a lower intensity and rate gradually increases as a result of oxygen deficiency in the introduction to the initial load there is overloading of the organism in terms of oxygen coverage, which ultimately reflects negatively on the final performance. The most objectively is possible to check the adequacy of the pace of walkers using the tester, when a current pulse rate can realistically assess the level of body burden. According to our findings, it is very important that the racer at least the first five minutes of the pulse rate does not exceed 95% ANT at 20 km race and just 95% of ANT in the race for 50 km.

Consistent with our previous research (Pupiš - Čillík, 2005; Pupiš - Savanovič - Štihec, 2009) the result shows that the walker is able to complete 20 km race at an average heart rate corresponding to around 104% ANT. On the 50 km race M.T. even reaches up to around 95-98% which is slightly greater value than we have in the past (Pupiš - Savanovič - Štihec, 2009). In previous studies we have to assess the intensity of the load in the relationship between ANT and the average heart rate for walkers at a lower performance level to 50 km (3:48:00 to 4:00:00 hours), where the performance level of M.T. is higher.

From the perspective of M.T. it is essential that the intensity of the load for the first 5 km race at 20 km does not exceed the average levels of ANT. The 50 km race showed that for M.T. is corresponding intensity for the first 10 km approximately 90% ANT.

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DEPENDENCE BETWEEN ANAEROBIC THRESHOLD AND MAXIMUM OXYGEN CONSUMPTION IN RACE WALKERS

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Abstract

The research deals with the dependence between anaerobic threshold and maximum oxygen consumption in the top athletes in race walking. Athletes completed 5 laboratory examinations at various stages of preparation, in which the level of anaerobic threshold and maximum oxygen consumption were assessed. Subsequently, the dependency between these two variables was detected. The research has shown that it is not possible to express any constant between the anaerobic threshold and maximum oxygen consumption, nevertheless it is possible to say that the oxygen consumption at anaerobic threshold achieved in top athletes – race walkers level between 80 to 100 percent of VO_{2max} .

Key words: Maximum oxygen consumption. Anaerobic threshold.

Problem

In endurance sports anaerobic threshold - ANT and VO_{2max} are considered to be the most objective indicators of training and race load, thereby they have become the main interest for many authors, among others Hagberg and Coyle (1983), Hamar (1989), and Choutka Dovalil (1991), Noakes (1991), and Truksa Kucera (2000), Chin et al. (2001), Power (2002), Broďáni (2002), Baker and Horton (2003), Soumar - Soulek - Kučera (2006), etc. Bunc et al. (1982) defined the ANT as the breaking point of curve reliance of lactate on the load. It is therefore a point until which the reliance had a linear character and from this point it passes to the dependence of mainly exponential nature. ANT can be considered as one of the most significant variables in regard to prediction of performance in endurance sports Bielik et al. (2006), equally important parameter is the VO_{2max} , a maximum amount of oxygen that the lungs are able to extract from the inhaled air and which is transported by blood to working muscles (Hájková, 1997).

We can often encounter opinions according to which two decisive boundaries for the development of endurance are anaerobic threshold and

VO₂max. Interdependence of these two parameters was tried to be defined by many authors (Seliger et al., 1980, Hamar, 1997; Dovalil, 2002, Moravec, 2004 and others) very similarly - in unexercised walkers share of maximum oxygen consumption at anaerobic threshold varies around 50% VO₂max, training can be increased to up to 80-90%. Based on these arguments, we see that anaerobic threshold (respectively. 80% of VO₂max) is considered to be the maximum intensity on the development of endurance. On the contrary, there is the argument of Kučera and Truksa (2000) that during the physical load of higher intensity than 70% VO₂max oxidation of lactic arises and then re-synthesis of glycogen is not sufficient to degrade all still forming lactic acid. In accordance with Bielik et al. (2006), we see a problem in the fact that the verification of training effectiveness at the level of ANT in the development of oxidative processes in the past took place mainly on a sample of untrained or only moderately trained subjects. Sport experience shows that it is not possible to compare the top athletes themselves in terms of functional abilities and adaptation to sports training, for this reason the comparison of average trained, respectively untrained persons is misleading and distorting. In the comparison of maximum oxygen consumption of untrained people (35-45 ml.kg⁻¹.min⁻¹) and top athletes (60-80 ml.kg⁻¹.min⁻¹) we can find that the level of oxygen consumption of top athlete at aerobic threshold is equivalent to the consumption of oxygen by the ANT, or even nearly to the maximum oxygen consumption in untrained individuals.

Hamar (1997) defined the anaerobic threshold as a dynamic balance between lactate (lactic acid salt) formed in the muscles and its removing from the heart and resting muscles. After overcoming these limits it comes to accumulation of the lactate and to internal disruption of the balance of the organism. Lactic acid as a strong acid is immediately dissociated into lactate anion and hydrogen cation which increased concentration causes metabolic acidosis of own internal environment of the organism (Soumar - Soulek - Kucera, 2006). It is therefore necessary to monitor the value of anaerobic threshold and VO₂max of each athlete, and then to define their relationship. In general, the value corresponding to the anaerobic threshold is considered to be the lactate concentration of 4 mmol.l⁻¹, but different authors (Saltin et al. 1995; Kučera - Truksa, 2000; Soumar - Soulek - Kucera, 2006) point out that this value is significantly lower in athletes (about 3,3 mmol.l⁻¹), while in the athletes in the 800 and 1500m this is a non-negligible higher contrast (up to 5,5 mmol.l⁻¹). Bielik et al. (2006) allows higher values for

distance athletes. Kučera and Truksa (2000) indicate that at the anaerobic threshold it is possible to work for 30-60 minutes, but while training it is appropriate to divide the load into a shorter time of 7-12 min. VO_2max is defined as a critical speed at which they can receive 8-12 min. duration of load, while the optimal training stimuli are 2-6 min. Moravec (2004) in the structure of endurance capacity gives as a medium endurance exercise corresponding to 95-100% VO_2max with a duration of 20-10 min. Costill (1977) described the load of ANT and VO_2max as anaerobic - aerobic zone, with the optimum time of the load 5-6 min. This zone is usually characterized by blood lactate concentration of 4 – 9 $\text{mmol}\cdot\text{l}^{-1}$. Generally speaking, the athlete usually achieves ANT rather than VO_2max , as shown in the Figure 1, which illustrates the heart rate during the examination at which was detected ANT and VO_2max simultaneously.

Aim of work

The aim of our work is to find out a dependence and relationship between anaerobic threshold and VO_2max in the top athletes in race walking when we want to quantify their relationship, which would be applicable to sport practice.

Methodology

Characteristics of the tested group

Representatives of the Slovak Republic in race walking:

- 1st - Age 28 years, body height 178 cm, weight 67 kg
- 2nd - Age 36 years, body height 174 cm, weight 62 kg
- 3rd - Age 35 years, body height 180 cm, weight 72 kg
- 4th - Age 29 years, body height 191 cm, weight 74 kg
- 5th - Age 33 years, body height 178 cm, weight 64 kg
- 6th - Age 29 years, body height 175 cm, weight 60 kg

Our monitored athletes completed five tests in different stages of their preparation to avoid possible errors caused by different levels of special fitness, which could more or less distort the results of our research. We have to consider the fact that on the research participated athletes racing on the 20 km and also on the 50 km. It means that athletes racing on the different distances can have greater differences in aerobic capacity as well as in aerobic performance. The identical methodology was used in all examinations, which consisted of a gradual increase in load (speed) on treadmill (similar form, as in Conconiho test). Monitored athletes received load by Conconiho test on a treadmill. They started at a very low intensity and then each minute increased the speed until the rejection. During this test we also studied anaerobic threshold, maximal aerobic power and aerobic capacity of the ventilation parameters in laboratory conditions. The group only consisted of representatives of the Slovak Republic who participated in the European Championship, World Championships or Olympic Games, which ensure a high level of scheduled sports athletes.

Results and discussion

Athletes, on whom we made our research, were subjected to laboratory testing - spiroergometer examination at various stages of preparation, but in spite of that they still exceeded even the lowest values of VO_2max and $60 \text{ ml.kg}^{-1}.\text{min}^{-1}$, when most values of $\text{VO}_2\text{max.kg}^{-1}$ were in the range of 70 to $80 \text{ ml.kg}^{-1}.\text{min}^{-1}$, which confirms the high aerobic performance and capacity of the organism in all studied athletes (Table 1). Our monitoring showed that the amount of oxygen consumption (VO_2max) for ANT was significantly lower (about $2\text{-}15 \text{ ml.kg}^{-1}.\text{min}^{-1}$) than the maximum reached VO_2max (Table 1). This confirms the statement that well-trained athletes are able to work (or even increase their power) even few minutes after overcoming of anaerobic threshold. This is also confirmed in our monitoring when athletes stepped load even few minutes after overcoming of a threshold.

Table 1 Comparison of selected parameters in anaerobic threshold and VO₂max

	HR of ANT (bpm)	HR VO ₂ max (bpm)	VO ₂ max at ANT (ml.kg ⁻¹ .min ⁻¹)	VO ₂ max (ml.kg ⁻¹ .min ⁻¹)	Puls O ₂ ANT (ml)	Puls O ₂ VO ₂ max (ml)	Ventilation n ANT (l.min ⁻¹)	Ventilation VO ₂ max (l.min ⁻¹)
1.	179	193	52,6	65,4	20,8	22,7	110,6	153,7
	173	175	54	62,9	20,6	23,7	111,8	149,8
	168	182	56,4	64,7	22,9	23,8	112,7	154,8
	169	186	48,5	59,3	21,7	23,5	109,5	153,6
	168	164	54,2	58,4	21,3	23,5	116,2	157,1
	171,4	180	53,14	62,14	21,46	23,44	112,16	153,8
2.	171	181	63,8	72,8	25	27	112	188,1
	162	175	63,1	69,5	24,5	26	118,5	163,7
	168	172	55,1	66,8	22,4	25,2	115,5	169,9
	175	170	63,9	68,1	23,4	25,6	125,4	187,7
	159	167	57,7	66,6	23,2	25,4	109,8	169,2
	167	173	60,72	68,76	23,7	25,84	116,24	175,72
3.	174	173	54,9	65	20,2	24	105,2	152
	171	183	51,6	66,3	19,6	23,5	104,3	149,7
	174	182	56,1	67,2	22,5	25,3	131,5	134,6
	174	192	59,9	66,2	26,6	26,8	143,2	177,8
	181	195	68,4	79,1	28,4	30,4	135,2	183,8
	174,8	185	58,18	68,76	23,46	26	123,88	159,58
4.	165	162	61,2	69,1	22,6	29,7	114,9	150,7
	169	194	60,7	73,9	24	27,8	109,4	155,4
	170	170	64,7	73,3	25,5	32,3	129,4	163,6
	161	166	53,4	63,7	21,2	24,6	127,8	160,6
	162	163	49,4	65	24,3	28,8	128,6	162,7
	165,4	171	57,88	69	23,52	28,64	122,02	158,6
5.	152	171	49,4	63,9	24,4	26,2	131,1	160,4
	170	166	64,2	73,3	25,5	32,3	133,6	154,8
	156	159	68,2	75,8	28,7	31	121,3	154,3
	170	191	65,8	75	24	25,4	123,2	160,2
	195	187	73,1	77	22,9	24,7	132,3	163,5
	168,6	174,8	64,14	73	25,1	27,92	128,3	158,64
6.	181	186	67,8	74,9	22,8	25,6	125,6	160,3
	178	177	79,9	89,5	26,5	29,8	140,7	186
	179	185	77,5	79	24,7	27,6	155	177,9
	178	181	68,9	75,8	24,9	26,9	152,1	179,4
	187	194	60,2	67,6	21,9	24,1	143,7	169,5
	180,6	184,6	70,86	77,36	24,16	26,8	143,42	174,62

The results obtained in our research are consistent with the authors' statements according to which oxygen reaches in the anaerobic threshold from eighty to ninety percent of the maximum. This result was reached by all six monitored athletes with the exception of three measurements when they mainly approached to the level of 90-100% (Fig. 2). This confirms the high effectiveness when working with oxygen in studied athletes and it is

one of the decisive factors in endurance performance. Of course, the maximum intensity has the decisive impact on the outcome in endurance sports when there is a greater production of lactate than the organism is capable to process, thus the intensity below the level of anaerobic threshold. On the other hand, the organism must be able to receive and process as much oxygen as possible however not absolutely but in conversion to kg of weight per minute of loading (i.e. its $\text{VO}_2\text{max.kg}^{-1}$ should be as high as possible).

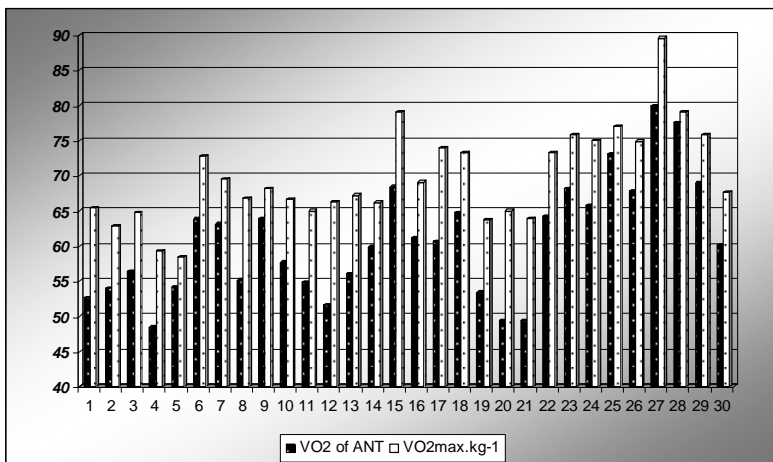


Fig. 1 Comparison of VO_2 in ANT and maximal VO_2max (1-5 (athlete-1), 6-10 (athlete-2), 11-15 (athlete-3), 16-20 (athlete-4), 21-25 (athlete-5), 26-30 (athlete-6))

As it can be seen in Figures 1 and 2 the highest percentage of maximum oxygen consumption was amounted in ANT for those measurements where the VO_2max also attains the highest absolute value. All these measurements, when athletes reached the highest absolute values of VO_2max as the highest levels of VO_2 in ANT have been made during the race season, which is in the phase when athletes reached the highest level of their fitness. In this period athletes reached the highest values of VO_2max and also the values of VO_2 in ANT were the closest to absolute VO_2max .

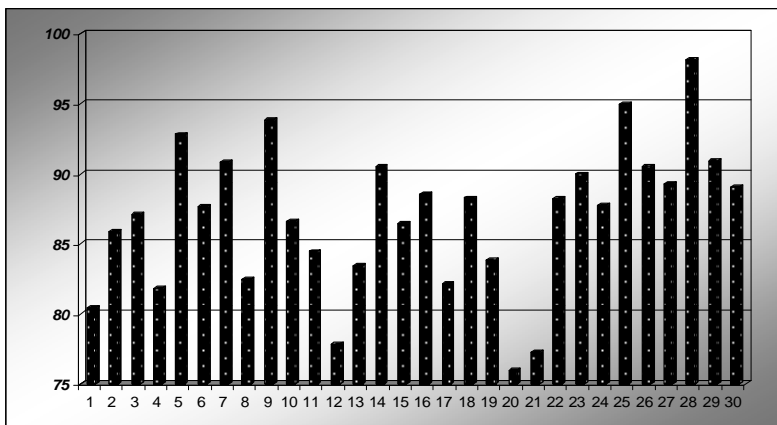


Fig. 2 Achieved VO₂ in ANT as a percentage (maximum of VO₂max) (1-5 (athlete-1), 6-10 (athlete-2), 11-15 (athlete-3), 16-20 (athlete-4), 21 -25 (athlete-5), 26-30 (athlete-6))

A part of our research was to compare the heart rate at anaerobic threshold and VO₂max during treadmill testing. We found out a remarkable discovery.

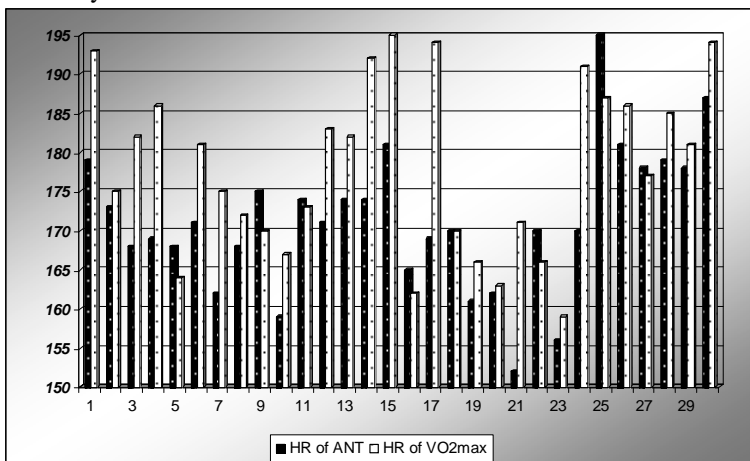


Fig. 3 Comparison of heart rate in ANT and HR of VO₂max (1-5 (athlete-1), 6-10 (athlete-2), 11-15 (athlete-3), 16-20 (athlete-4), 21-25 (athlete-5), 26-30 (athlete-6))

Heart rate at anaerobic threshold was in eight cases (out of 30) higher than at VO_2max (Figure 3) but when we realized the methodology of Conconi test we found out that our research only confirmed the principles on which Conconi based his test which was created to determine the ANT in the field.

Figure 4 shows that the heart rate reached at the anaerobic threshold from 87 to 103% of heart rate in VO_2max , so after overcoming of ANT a heart rate raised either very slowly or, in some cases, even it was only for a maximum of 3 percent, declined. On the other hand, oxygen consumption raised regardless of the fact whether the heart rate after overcome an ANT increased, or decreased, as confirmed by Figure 1. Based on the interpretation of the Conconi test by Pupiš and Korčok (2003), the heart rate increases to the level of anaerobic threshold linear and at the point of the ANT the line deviates towards the x-axis (and thus it can also decline), this fact is consistent with their interpretation. The organism's ability to take as much oxygen as possible per kg of weight per minute has no limits but the heart rate it means that the oxygen consumption can increase even after overcoming this threshold.

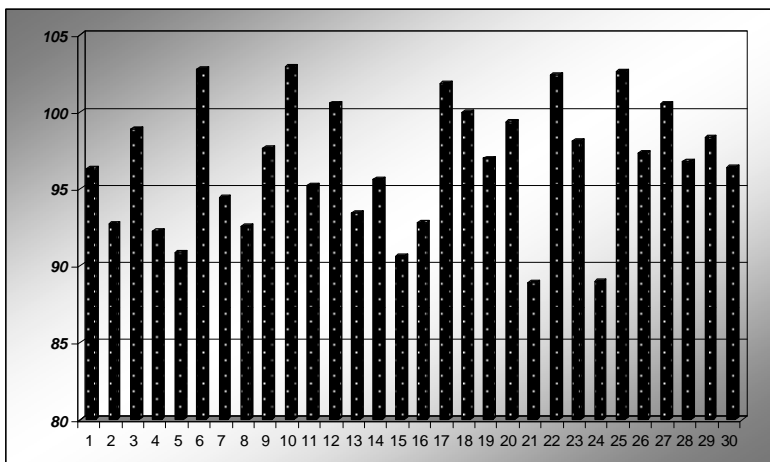


Fig. 5 The level of heart rate in VO_2max and ANT (in percentage of heart rate at VO_2max) (1-5 (athlete-1), 6-10 (athlete-2), 11-15 (athlete-3), 16-20 (athlete-4), 21-25 (athlete-5), 26-30 (athlete-6))

Conclusions

The research that we had implemented showed us that the relationship between anaerobic threshold and $VO_2\text{max}$ cannot be expressed by any constant, but nevertheless it is possible to say that the VO_2 in anaerobic threshold achieves in the top athletes – race walkers level between 80 to 100 percent of $VO_2\text{max}$, however, it must be defined for each athlete individually. Only then we can determine the intensity of training load, because each percentage point in the intensity may mean an error in wrongly fixed intensity. Equally important is to properly measure the length of the load on the level of ANT respectively $VO_2\text{max}$.

Monitoring of the heart rate under the load on a treadmill showed that after overcoming the limits of ANT it comes not only to a distortion of dynamic equilibrium between lactate forming in the muscles and its removing in the heart, but also it interrupts the linear increase of their heart rate and even it may lead to an increase in heart frequency after overcoming this barrier. This fact must be taken into account in particular for high intensity training sessions at the level of ANT, because after overcoming of ANT a heart rate control may lose its importance. Even low heart rate may wrongly "highlight" the low training deployment. As a result of inexperience, the coach can suspect the athlete from laxity. The tester should not be the only control mechanism in training and therefore it is essential to monitor other indicators as well such as: lactate, creatine kinase, pH, blood pressure, etc. As each organism has its own specificity, we consider that it is also important to verify the effectiveness of an individual training at the ANT because there are also some views that do not incline to the method of developing of the endurance at ANT. Training at the level of ANT is considered to be demanding on use of glycogen, whose recovery is limited and does not give sufficient stimulus for physiological adaptation in the development of race rate. From the perspective of our research sample we consider the ANT as a very important indicator because according to a Pupiš and Čillík (2005) the athletes complete the races in 20 km in the intensity of 100% - 102% ANT and longer races (50 kilometres) on the Olympic distance at 92%-95% ANT. The knowing of the threshold allows athletes to better estimate the appropriate race rate.

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SEXUAL INTERCOURSE AND RACE WALKING PERFORMANCE

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Abstract

The research was to investigate the influence of sexual activity race walkers before varied types of load. A group of subjects was composed of 37 race walkers from 6 European countries aged from 32 ± 6 years, who completed a questionnaire. It was composed of 8 questions with a lot of subquestions. The research proves that all race walkers do not respond equally after being exposed to sexual intercourse in terms of their performance whereby more than 90 % of the observed subjects accented that sexual intercourse 12 hours before the load would not have negative influence on the obtained results. Sexual intercourse 30 minutes before the load (training or competition) is practiced by 1/6 of race walkers whereby 1/3 of them noticed the achievement of worse sports results after such activities. Majority of athletes agrees that sexual intercourse 12 hours before the load will not cause negative effects on the performance.

Key words: race walkers, sexual intercourse

Problem

Some studies indicate athletes need more sex than non-athletes (Connelly, 1994). Different studies suggest that pre-sports sex may actually aid athletes by raising their testosterone levels, for example (Lovgren, 2006). Sexual activities immediately before sports competitions have been widely addressed and discussed by athletes and experts in this area but their attitudes towards this topic are diverse (James, 1990; Anderson & Morgan, 1994; Chidley, 1996; Pupiš & Štihec, 2009; Pupiš et al, 2010). However, sexual activity is a part of everyday life of most people, i.e. athletes. Their attitudes are so different depending on the type of sport that we have determined to tackle this problem in the current paper which is a part of the project VEGA 1/0322/10 (Optimalization of performance in

individual sports). Similar study was conducted with the American footballers and baseball players showing that American football players restrain from having sexual intercourses before the match, contrary to the baseball players. As we were taking, on the other hand, it turned out that athletes are generally speaking more sexually active than non-athletes (Fisher, 1997). It was also revealed that team sports athletes were more prone to pre-marital sexual intercourse and thus more frequent sexual partners exchange while individual sports athletes were more conservative in this respect. Tracing back the past it is well known that Mohamed Ali avoided sexual activities 6 weeks prior to boxing matches (Fisher, 1997), and even today a lot of coaches forbid athletes any sexual activities. However, a footballer player George Best claims that he had had sexual intercourses even during a half time. According to the research of Booneho & Gilomora (1995), published in the Journal of Sports Medicine and Physical Fitness, sexual intercourse should not exert negative influence on sports performance.

One argument for abstaining from sexual intercourse the night before an enduring athletic workout is that being sexually frustrated can lead to increased aggression. Evidence, however, suggests that sexual intercourse the night before an event does not alter physiological testing results, the latter of which was measured by strength and endurance of the palmar flexing muscles McGlona & Shriera (2000). Similarly, a randomized crossover study found that oxygen pulse, maximal aerobic power, and double product were not significantly affected by sexual intercourse 12 hours prior to the athletic performance Booneho & Gilomora (1995). The most aggressive lovemakers burn about 250 calories an hour, or 4 calories per minute. The average person makes love for only five minutes and burns fewer than 25 calories. However, a lack of sexual intercourse can result in diminished and disturbed sleeping and consequently psychological anxiety and exhaustion.

Sexologist Trojan (2006) completely agrees with this finding and claims that an athlete who does not have a sexual intercourse the whole night long but just the evening before the competition and a good night sleep afterwards can not induce bad results. He himself would not recommend sexual intercourse as an ideal warm up activity in the morning before the competition but it would certainly have a positive effect on the results. According to the same author theories of increased competitive condition of

sexually inactive contestants are not validated. Competitive sporting spirit could be theoretically connected to the level of testosterone which in turn induces an increase in sporting spirit. However it was found that the level of testosterone is not affected after the sexual intercourse. Two hours after sexual activities a level of prolactine is increased which does not affect sports performance at all (Trojan, 2006). This is in accord with the research of McGlona & Shriera (2000) and Andersona, Weia, & Shyu (2001), who claim that no changes were notices in the athletes results 12, i.e. 48 hours after sexual intercourse. Sports physician Pavol Malovič claims that sexual intercourse is a normal activity the same as when you run up the stairs to the second floor, which corroborates the claim that it can not have negative effects on the results in sport. He adds that sexual activity has a vital role and is classified as one of the best rehabilitation activities for the spinal column. It increases the level of the positive hormone - endorfine, inervates pelvis, etc. (Mikulová, 2003). Yet Douglas (2007) does not recommend sexual intercourse immediately before the competition because the ejaculation as he claims induces drowsiness. Also, doctor Boytova has no clear attitude towards this topic but does not recommend sexual intercourse to men immediately before the competition, but she does not make an issue of it.

Aim

The aim of this study was to investigate the influence of sexual activity race walkers before varied types of load.

Methodology

Our research was carried out with the race walkers. A group of subjects was composed of 37 race walkers from 6 European countries aged from 32 ± 6 years, who completed a questionnaire. It was composed of 8 questions with a lot of subquestions. All subjects were elite athletes and one of the research subjects was world champion in athletics. Subjects were given a diary to track all their feelings about sexual relations within 6 weeks.

Results

In the first part of our research we were observed the load the very sexual intercourse put on our subjects and have concluded that this activity is aerobic, mainly small and medium intensity which depended on the type of intercourse. Values of lactates measured right after the intercourse are 2,2 to 3,6 mmol.l⁻¹, and maximal values of heart rates go to 140 bpm. Blood

pressure increased of 30-50 mmHg. A group made up of 6 race walkers was observed for the changes in heart rates in loads ensued 48 after the sexual intercourse, 30 minutes and 12 hours after the sexual intercourse. Differences in average values of heart rates in aerobic loads lasting to 1 hour (rhythm $\pm 0,9$ s / km) were minimal. Also load with heart rates to the limit of 136 bpm was observed. Difference between these heart rates was $0,2 \text{ p.min}^{-1}$ which is a neglect table value for sport.

Similar situation occurred with the load with the intensity of tempo lasting to 2 hours (tempo $\pm 0,5$ s / km). Heart rate reached average value of 153 bpm, where the difference ranged from 0,4 bpm. These differences are also insignificant regarding sports.

We were noticed difference in the loads of higher intensity (in rhythm intensity of 95 % of ANT in standard circumstances). In loads longer than 4 minutes average heart in loads 48 hours after the sexual intercourse, i.e. 12 hours after the intercourse reached 3,9 bpm, i.e. $3,5 \text{ p.min}^{-1}$ higher values whereby subjective feelings did not change during loads. Only in loads 30 minutes after the sexual intercourse some weakness was felt but without negative influence on the realization of load.

We were noticed biggest differences in the loads of varied intensity known as fartlec training where observed race walkers realized tracks of 200 m of high intensity with the changes of 200 m lower intensity and thus 4km in the rhythm that corresponded to the value of the average heart rate on the limit of ANT (in standard circumstances). Again the smallest average heart rate in loads after 30 minutes upon sexual intercourse was registered and that 4,5 bpm, i.e. 6 p.min^{-1} , where there were no significant changes in subjective feelings. Only subjective feeling of decreased muscle tone was registered and it minimally disturbed the coordination in the first kilometer.

In the second part of our research were race walkers completed questionnaire. Based on the answers given we have found out that 16,22 % of race walkers state that it is correct to refrain from sexual activities just before the competition. On the other hand 83,78 % of race walkers have the opposite attitude. In relation to a given time interval 13,51 % of race walkers think that they should not have sexual intercourses 12 hours prior to load and 67,6 % consider any sexual contact 30 minutes before the sustainable load is not recommended. Worse results in the anaerobic load (above the anaerobic threshold) 12 hours after sexual activities are registered in 16,22 % of race walkers, in load of 90 % of ANT (anaerobic

threshold), 13,51 % reports decreased ability while in loading such as tempo training and the loading of aerobic character we do not register any worse parameter (as can be seen in Fig. 1).

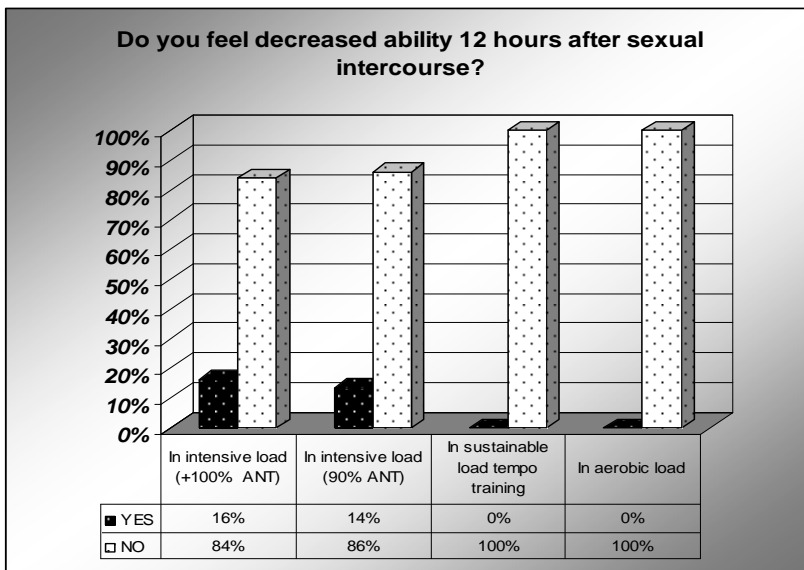


Fig. 1 The influence of sexual intercourse on the sustainable load 12 hours before the different loads

Race walkers registered worse results in the anaerobic load (above the anaerobic threshold) 30 minutes after sexual activities in 32,43 % , in loads of 90 % of ANT (anaerobic threshold) 40,54 % reports decreased ability, while in loading such as tempo training 37,83 % report decreased ability. In loading of aerobic character we do not register any worse parameter (as can be seen in Fig. 2). One observed race walkers basically refrains from such activities before the described loads while the other one reports no such recent experiences to make conclusions about this topic.

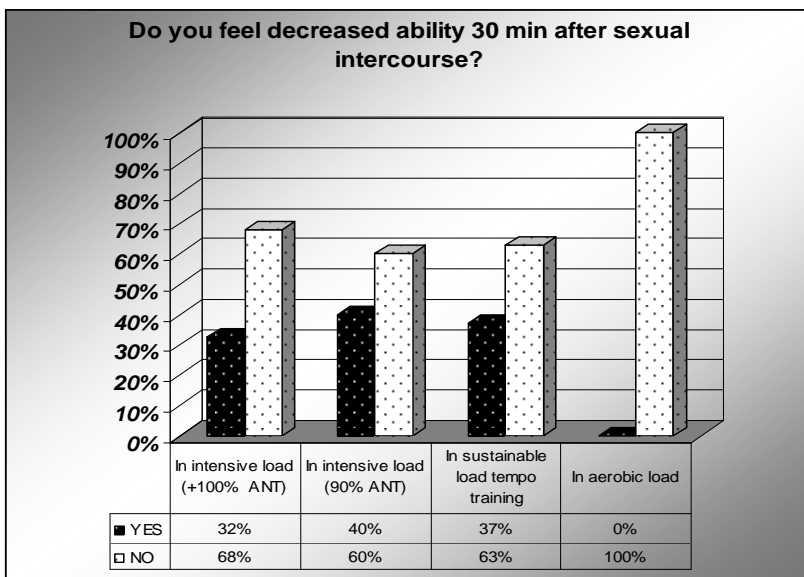


Fig. 2 The influence of sexual intercourse on the sustainable load 30 minutes before the different loads

In time of 12 hours after sexual intercourse none of the race walkers register complete weakness, waste of energy is reported in just 5,40 %, and decreased coordination is reported in 10,80 % of race walkers (Fig. 3). Increased tension is not reported at all but overwhelming relaxation is felt in 32,4 % of the race walkers. We do not register weaker concentration even 12 hours after the sexual intercourse.

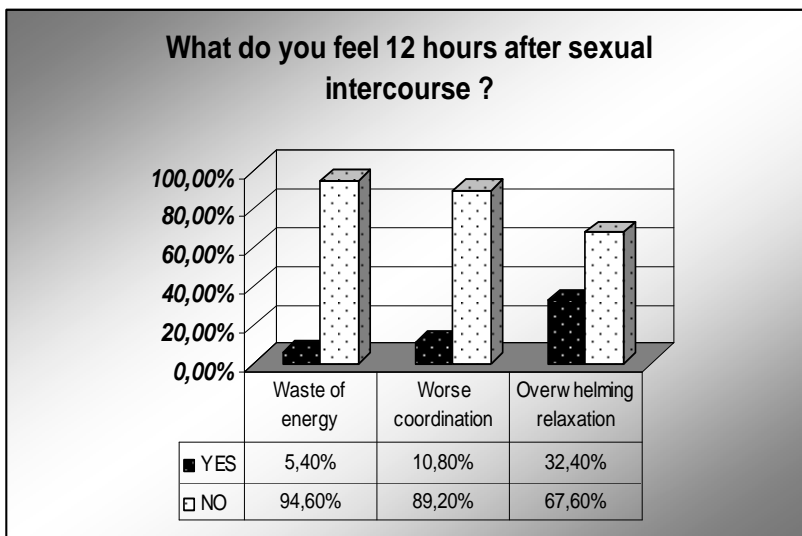


Fig. 3 The influence of sexual intercourse of subjective feelings in sustainable loads 12 hours after the sex

In time of 30 minutes after the sexual intercourse in load 37,83 % of our subjects feel complete weakness and 40,54 % feel loss of energy. Worse coordination during loading is reported in 37,83 % of the subjects (Fig. 4). Disturbed concentration is noticed in 32,4 % of race walkers.

All race walkers of the research had sexual intercourse 12 hours before the competition and 16,22 % of them reported positive influence on their performance and obtained results, nobody reported negative feelings about this experience and attributed negative influence on their results while 83,78 % of them think that sexual intercourse did not exert any type of influence on their performance (neutral influence).

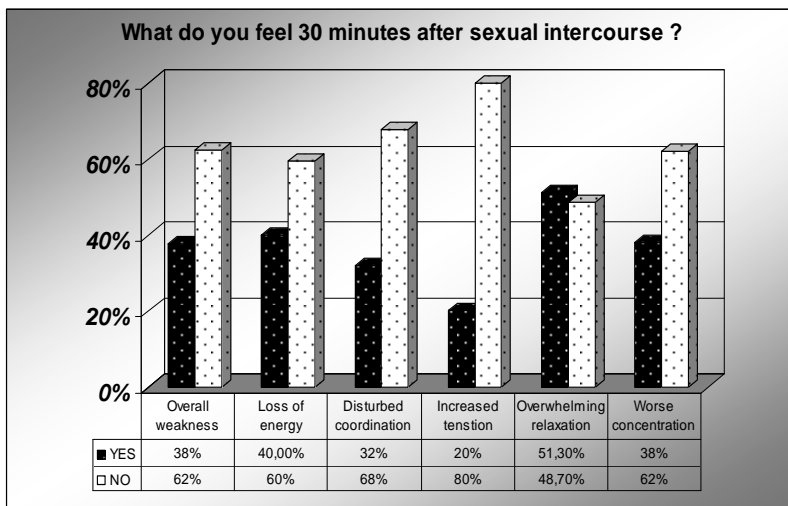


Fig. 4 The influence of sexual intercourse of subjective feelings in sustainable loads 30 minutes after the sex

Only 13,51 % of the observed race walkers had sexual intercourse 30 minutes prior to competition and 1/3 of the subjects think sex has negative influence on the achievement of results while 2/3 think that sex did not influence the results of the competitions. 5,4 % of race walkers do not have sexual intercourse 12 hours before the competition while 54,05 % of them refrains from sex 30 minute before the competition. It is understandable that a sexual intercourse 30 minutes long is hard to obtain, and one of our subjects think it even impossible but let us remind that 16,22 % of our subjects underwent such experiences.

Conclusion

The research proves that all race walkers do not respond equally after being exposed to sexual intercourse in terms of their performance whereby more than 90 % of the observed subjects accented that sexual intercourse 12 hours before the load would not have negative influence on the obtained results. Almost half of the observed subjects noticed change in muscle tension 30 minutes and 12 hours after the sexual intercourse. It is important to emphasize that 12 hours after the sexual intercourse only quite relaxing

feeling is reported while 20,27 % race walkers felt increased muscle tension 30 minutes after sexual intercourse. Even 40,54 % of the subjects felt worse feeling in loads of high intensity 30 minutes after the sexual intercourse but such activity of the body causes lower heart rates. In aerobic load of lower intensity there were no changes of subjective feelings and heart rates. Sexual intercourse 30 minutes before the load (training or competition) is practiced by 1/6 of race walkers whereby 1/3 of them noticed the achievement of worse sports results after such activities. More as half of group of race walkers agrees that sexual intercourse 12 hours before the load will not cause negative effects on the performance. It is to be concluded that it is not quite possible to determine whether sexual intercourse before the load exerts positive or negative influence on the achievement of results.

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PHYSIOLOGICAL VARIABLES RELATED TO 20 KM RACE WALK PERFORMANCE

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Abstract

This study provides new data on an athletics event group that has received scant attention in the academic literature. In highly trained male and female athletes competing in the 20 km race walk event velocity at lactate turnpoint and velocity at maximum oxygen uptake correlate with performance. Relationships between physiological variables and performance may be indicative of the intensities at which the race distance is performed. Moreover differences in race walking economy may discriminate between performers exhibiting similarities in other physiological variables.

Key words: Race Walking; Performance; Training; Lactate Turnpoint; Oxygen Uptake; Race Walking Economy.

Problem

Little is known regarding the physiological determinants of elite race walking performance as previous studies have considered heterogeneous groups (Hagberg and Coyle, 1983, male 20 km, $n = 8$; Reilly *et al.* 1979, male 20 km, $n = 9$; Dunster *et al.* 1993, female 10 km, $n = 12$; and Yoshida *et al.* 1989, female 5 km, $n = 8$ and 1990, female 5 km, $n = 5$). High level performance in the 20 km race walk events is sub ~1 hr 26 min for male and sub ~1 hr 40 min for female athletes. This level of performance equates to mean competition velocities of ~14.0 km·h⁻¹ or faster and ~12.0 km·h⁻¹ or faster for male and female athletes respectively (Castellini, 2005).

Aim

Therefore the purpose of this study was to examine the relationship between selected physiological variables identified during race walking exercise on a

laboratory based motorised treadmill and 20 km competition performances of male and female race walkers from the UK Athletics Race Walking Squad.

Methodology

Seventeen male and twelve female athletes from the UK Athletics Race Walking Squad volunteered for this study, which had University ethical approval. Age (y), height (m), body mass (kg), body fat (%) and performance characteristics (race time, IAAF points and mean race speed) of the subjects are detailed in Tables 1 and 2.

The athletes completed between six and nine 4-minute stages of race walking on a motorised treadmill. All tests began at a 1% gradient, increasing by 0.5 km·h⁻¹ each stage, with a starting speed 2.0 km·h⁻¹ below the current race speed for 10 km of the subject. On completion of each stage a 20 µl arterialisised capillary blood sample was obtained from the ear lobe for the determination of blood lactate (B_{lac}) values. Expired air was collected into a Douglas bag for the last 60 s of each stage to determine oxygen uptake (VO_2) and race walking economy (ml O₂·kg⁻¹·km⁻¹). When heart rate (HR) exceeded 95 % of the predicted maximum or B_{lac} exceeded 4 mmol·l⁻¹ the treadmill gradient was increased by 1% every 60 s. The test continued until volitional exhaustion for the determination of maximum oxygen uptake (VO_{2max}).

The velocity at lactate turnpoint (v-LTP) was the race walking speed at which there was an abrupt and exponential increase in B_{lac} values (Jones, 2007). The velocity at VO_{2max} (v- VO_{2max}) was resolved by linear regression on sub-maximal race walking speed and VO_2 values. Physiological data was compared with competition performance during a period of four weeks pre or post-test to minimise changes in aerobic conditioning (Jones and Doust (1997).

Table 1. Physical characteristics of the subjects . Anthropometric data was recorded in the laboratory prior to discontinuous incremental treadmill race walk test to volitional exhaustion.

		Age (y)	Height (m)	Body mass (kg)	Body fat (%)
♂	Mean ± SD	29 ± 8	1.78 ± 0.02	70.7 ± 6.8	12.0 ± 3.8
		(n=17)	(n=17)	(n=17)	(n=16)
♀	Mean ± SD	29 ± 5	1.64 ± 0.08	54.3 ± 5.9	21.9 ± 2.5
		(n=12)	(n=12)	(n=12)	(n=12)
♂ ♀	Mean ± SD	29 ± 7	1.72 ± 0.08	63.9 ± 10.4	16.3 ± 6.0

Table 2. Performance characteristics of the subjects . Race times (hh:mm:ss) convert to mean race speed ($\text{km}\cdot\text{h}^{-1}$). Performances correspond to point scores from the IAAF Scoring Tables (Szabo, 2003). Competition performance was only taken from a period of four weeks pre or post-test to minimise changes in aerobic conditioning (Jones and Doust (1997).

		20 km (hh:mm:ss)	IAAF points	v-20 km ($\text{km}\cdot\text{h}^{-1}$)
♂	Mean ± SD	01:31:13 ± 00:04:12	986 ± 75	13.2 ± 0.6
		(n=17)	(n=17)	(n=17)
♀	Mean ± SD	01:48:32 ± 00:05:52	982 ± 60	11.1 ± 0.6
		(n=12)	(n=12)	(n=12)
♂ ♀	Mean ± SD	01:38:23 ± 00:09:57	984 ± 68	12.3 ± 1.2

Outcomes

The physiological and descriptive data obtained during the discontinuous incremental treadmill race walk test to volitional exhaustion is displayed in Table 3. Results indicated that in athletes from the UK Athletics Race Walking Squad there were strong relationships between v-20 km and v-LTP and VO_{2max} in male athletes and between v-20 km and v- VO_{2max} in female athletes.

Table 3. Physiological and descriptive data obtained during discontinuous incremental treadmill race walk test to volitional exhaustion. The v-20 km is included for comparative purposes. Values in parenthesis are indicative of the number of subjects in which a particular variable was identified.

	v-20 km (km·h ⁻¹)	VO_{2max} (l·min ⁻¹)	VO_{2max} (ml·kg ⁻¹ ·min ⁻¹)	v- VO_{2max} (km·h ⁻¹)	LTP (mmol·l ⁻¹)	v-LTP (km·h ⁻¹)	VO_2 at LTP (ml·kg ⁻¹ ·min ⁻¹)	Fraction of VO_{2max} at LTP (%)	Race walking economy (ml O ₂ ·kg ⁻¹ ·km ⁻¹ at 12 km·h ⁻¹)
♂									
Mean	13.2	5.0	70.1	14.8	2.8	13.4	62.0	87	258.1
± SD	0.6	0.5	8.2	1.0	0.9	0.8	6.2	6	24.3
	(n=7)	(n=6)	(n=6)	(n=7)	(n=7)	(n=7)	(n=4)	(n=3)	(n=15)
♀									
Mean	11.1	3.1	56.7	12.9	2.9	11.8	50.6	89	257.8
± SD	0.6	0.6	7.3	0.7	1.3	0.5	8.9	8	44.9
	(n=2)	(n=2)	(n=2)	(n=2)	(n=2)	(n=2)	(n=2)	(n=2)	(n=11)
♂♀									
Mean	12.3	4.2	64.8	14.0	3.0	12.8	57.3	89	258.0
± SD	1.2	1.1	10.5	1.3	1.1	1.0	9.4	7	33.7

Analysis of variance and correlations between variables

The velocity during a 20 km race (v-20 km) for male and female athletes was significantly different from v-LTP and v-VO_{2max} ($p < 0.05$). In male athletes velocity at lactate turnpoint (v-LTP) had the strongest correlation with v-20 km ($r = 0.740$, $p < 0.05$, Table 4a). In female athletes velocity at VO_{2max} (v-VO_{2max}) had the strongest correlation with v-20 km ($r = 0.789$, $p < 0.05$, Table 4b). Based on the outcome of the present study the results suggested that the most important variables to examine when investigating variance in race walking performance were v-LTP and v-VO_{2max}.

Explanations of variance in performance

The adjusted R² value derived from multiple stepwise linear regression in Table 5a indicated that 53 % of the variance in male v-20 km was explained by variance in v-LTP and the addition of the variance in VO_{2max} (ml·kg⁻¹·min⁻¹) to the variance in v-LTP explained 71 % of the variance. The other statistically significant correlates with v-20 km (v-VO_{2max}, $r = 0.690$, $p < 0.05$; VO₂ at LTP, $r = 0.578$, $p < 0.05$) did not add to the regression and were excluded by the stepwise model. In female athletes the adjusted R² value indicated that 59 % of the variance in female v-20 km was explained by variance in v-VO_{2max} (Table 5b). The other statistically significant correlate with v-20 km (v-LTP, $r = 0.620$, $p < 0.05$) did not add to the regression and was excluded by the stepwise model.

The multiple stepwise linear regression models gave different explanations of variance in 20 km performance between male and female athletes, i.e. the submaximal variables v-LTP in males and v-VO_{2max} in females. However v-LTP and v-VO_{2max} did both correlate with v-20 km: v-VO_{2max} with v-20 km in males ($r = 0.690$, $p < 0.05$); and v-LTP with v-20 km in females ($r = 0.620$, $p < 0.05$). The truncated product method (TPM) was used in the analysis of the 20 km race walk events. When combining p values for Pearson's product moment correlation coefficients v-LTP, VO_{2max} and v-VO_{2max} TPM gave $p < 0.01$ for both male and female athletes, indicating all statistically significant results in the data set added to the level of significance and were not due to chance. Analysis of covariance identified that gender did not make a significant contribution to regression equations of the independent variables in the male and female groups. Therefore a

common regression line was drawn to estimate the linear relationship between v-20 km and the independent variables presented as male and female subject group scatter plots in Figures 1 to 3.

Table 4a. Correlation coefficients (r) for male 20 km athletes and descriptive data obtained during discontinuous incremental treadmill race walk test to volitional exhaustion. * = $p < 0.05$.

Male athletes	$\text{VO}_{2\text{max}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	v- $\text{VO}_{2\text{max}}$ ($\text{km}\cdot\text{h}^{-1}$)	LTP ($\text{mmol}\cdot\text{l}^{-1}$)	v-LTP ($\text{km}\cdot\text{h}^{-1}$)	VO_2 at LTP ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	Fraction of $\text{VO}_{2\text{max}}$ at LTP (%)	economy ($\text{ml O}_2\cdot\text{kg}^{-1}\cdot\text{km}^{-1}$)
v-20 km ($\text{km}\cdot\text{h}^{-1}$)	0.64* ($n=16$)	0.69* ($n=17$)	-0.39 ($n=17$)	0.74* ($n=17$)	0.59* ($n=15$)	-0.35 ($n=14$)	-0.12 ($n=15$)
$\text{VO}_{2\text{max}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)		0.47 ($n=16$)	0.10 ($n=16$)	0.29 ($n=16$)	0.82* ($n=14$)	-0.57 ($n=14$)	0.51 ($n=15$)
v- $\text{VO}_{2\text{max}}$ ($\text{km}\cdot\text{h}^{-1}$)			-0.42 ($n=17$)	0.84* ($n=17$)	0.20 ($n=15$)	-0.53 ($n=14$)	-0.36 ($n=15$)
LTP ($\text{mmol}\cdot\text{l}^{-1}$)				-0.35 ($n=17$)	0.33 ($n=15$)	-0.22 ($n=14$)	0.41 ($n=15$)
v-LTP ($\text{km}\cdot\text{h}^{-1}$)					0.24 ($n=15$)	-0.16 ($n=14$)	-0.46 ($n=15$)
VO_2 at LTP ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)						-0.01 ($n=14$)	0.58* ($n=14$)
F $\text{VO}_{2\text{max}}$ at LTP (%)							-0.12 ($n=14$)

Table 4b. Correlation coefficients (r) for female 20 km athletes and descriptive data obtained during discontinuous incremental treadmill race walk test to volitional exhaustion. * = $p < 0.05$.

Female athletes	VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	$v \cdot VO_{2max}$ ($km \cdot h^{-1}$)	LTP ($mmol \cdot l^{-1}$)	$v \cdot LTP$ ($km \cdot h^{-1}$)	VO_2 at LTP ($ml \cdot kg^{-1} \cdot min^{-1}$)	Fraction of VO_{2max} at LTP (%)	Race walking economy ($ml O_2 \cdot kg^{-1} \cdot km^{-1}$ at 12 $km \cdot h^{-1}$)
v-20 km ($km \cdot h^{-1}$)	0.39 ($n=12$)	0.79* ($n=12$)	-0.32 ($n=12$)	0.62* ($n=12$)	-0.15 ($n=12$)	-0.29 ($n=12$)	-0.04 ($n=11$)
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)		0.11 ($n=12$)	0.09 ($n=12$)	-0.00 ($n=12$)	0.27 ($n=12$)	0.17 ($n=12$)	0.78* ($n=11$)
$v \cdot VO_{2max}$ ($km \cdot h^{-1}$)			-0.38 ($n=12$)	0.72* ($n=12$)	-0.34 ($n=12$)	-0.45 ($n=12$)	-0.36 ($n=11$)
LTP ($mmol \cdot l^{-1}$)				-0.21 ($n=12$)	0.59* ($n=12$)	0.58 ($n=12$)	0.19 ($n=11$)
$v \cdot LTP$ ($km \cdot h^{-1}$)					0.028 ($n=12$)	0.14 ($n=12$)	-0.24 ($n=11$)
VO_2 at LTP ($ml \cdot kg^{-1} \cdot min^{-1}$)						0.83* ($n=12$)	0.57 ($n=11$)
F VO_{2max} at LTP (%)							0.53 ($n=11$)

Table 5a. The adjusted R^2 value indicates that 62 % of the variance in male v-20 km was explained by variance in v-LTP (model 1) and the addition of the variance in VO_{2max} to the variance in v-LTP explained 74 % of the variance (model 2).

20 km race walk Male athletes			Multiple stepwise linear regression		
Model number	Variables	Correlation coefficient (r)	Multiple r^2	R^2	Adjusted R^2
1	v-LTP ($\text{km}\cdot\text{h}^{-1}$)	0.74	0.74	0.56	0.53
2	v-LTP ($\text{km}\cdot\text{h}^{-1}$) & VO_{2max} ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	0.64	0.87	0.75	0.71

Table 5b The adjusted R^2 value indicates that 59 % of the variance in female v-20 km was explained by variance in v- VO_{2max} .

20 km race walk Female athletes		Multiple stepwise linear regression		
Variables	Correlation coefficient (r)	Multiple r^2	R^2	Adjusted R^2
v- VO_{2max} ($\text{km}\cdot\text{h}^{-1}$)	0.79	0.79	0.62	0.59

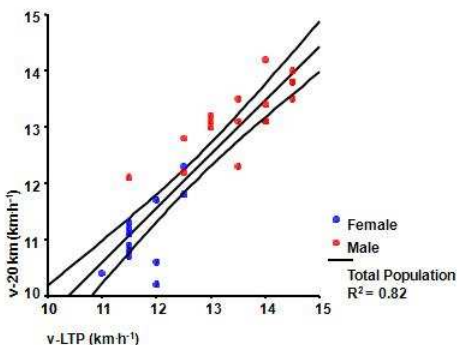


Fig. 1 The relationship between 20 km performance speed and the velocity at lactate turnpoint (v-LTP) in male and female athletes with the linear relationship estimated by the common regression line fitted to the data. The lines fitted above and below show the 95 % confidence intervals of the mean relationship between the variables.

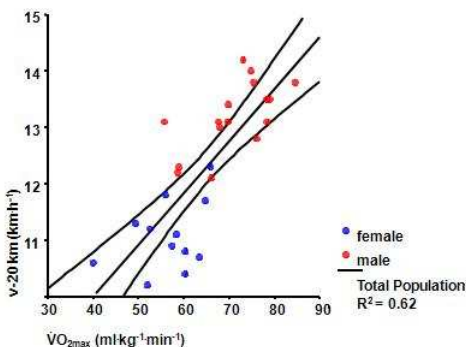


Fig. 2 The relationship between 20 km performance speed and VO_{2max} in male and female athletes with the linear relationship estimated by the common regression line fitted to the data. The lines fitted above and below show the 95 % confidence intervals of the mean relationship between the variables.

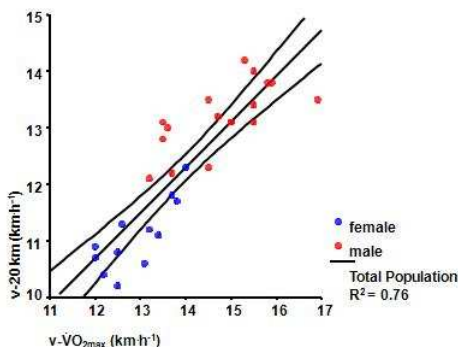


Fig. 3 The relationship between 20 km performance speed and the velocity at VO_{2max} ($v-VO_{2max}$) in male and female athletes with the linear relationship estimated by the common regression line fitted to the data. The lines fitted above and below show the 95 % confidence intervals of the mean relationship between the variables.

Discussion

Maximum oxygen uptake

The male athletes' mean VO_{2max} values ($70.1 \pm 8.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $n = 17$) were similar to those reported by Reilly *et al.* (1979) ($70.0 \pm 3.0 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $n = 9$), Brisswalter *et al.* (1998) ($70.6 \pm 4.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $n = 9$), Franklin *et al.* (1981) ($62.9 \pm 4.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $n = 9$) and Hagberg and Coyle (1984) ($58.1 \pm 1.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $n = 8$). The female athletes mean VO_{2max} of $55.7 \pm 8.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ is similar to the values reported by Dunster *et al.* (1993) ($57.3 \pm 7.7 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $n = 12$) and Yoshida *et al.* (1989 and 1990) ($49.8 \pm 2.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $n = 8$ and $49.9 \pm 3.0 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $n = 5$). So the athletes taking part in the present studies attained a similar profile in terms of VO_{2max} as other elite level race walkers.

20 km performance did correlate with VO_{2max} in male ($r = 0.64$, $p < 0.05$, $n = 31$) but not female athletes ($r = 0.39$, $p > 0.05$, $n = 12$). These results showed some contradictions with previous researchers, e.g. VO_{2max} did not correlate with 20 km race walk performance in the male athletes studied by Hagberg and Coyle (1983) ($r = 0.62$, $p > 0.05$, $n = 8$) or Reilly *et al.* (1979) ($r = 0.53$, $p > 0.05$, $n = 9$) but Yoshida *et al.* (1989) found a significant

correlation between $\text{VO}_{2\text{max}}$ and female 5 km walk performance ($r = 0.74$, $p < 0.05$, $n = 8$). This may reflect the lower subject numbers in the studies by these authors or the relative homogeneity of the subject group in the present study, i.e. the more homogenous the group, the less likely statistical significance as demonstrated in literature relating marathon running performance to $\text{VO}_{2\text{max}}$ (Maughan and Leiper, 1983; Sjödin & Svedenhag, 1985). Moreover, the mean 20 km performance of the male athletes studied by Hagberg and Coyle (1983) was 1 h 52 min \pm 6 min, which was much slower than the 1 h 31 min \pm 4 min of the male athletes in the present study.

Although $\text{VO}_{2\text{max}}$ did not correlate with female race walking performance $v\text{-VO}_{2\text{max}}$ explained a large segment of variance among the female athletes 20 km race pace: 59 % by variance in $v\text{-VO}_{2\text{max}}$ when entered into the stepwise multiple linear regression analysis (Table 5b). In a study of 5 km cross country running performance peak exercise treadmill grade at the termination of a running test to volitional exhaustion was the strongest correlate among physiological variables examined by Berg *et al.* (1995), which is a similar method to that used to determine $v\text{-VO}_{2\text{max}}$ in the present study. The $\text{VO}_{2\text{max}}$ values recorded by the female subjects ($56.7 \pm 7.3 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $n = 12$), like the male athletes, were similar to those reported for other high level female race walkers and endurance athletes.

Blood lactate variables

The variables related to B_{lac} were closely correlated with the male athletes $v\text{-20 km}$ in particular $v\text{-LTP}$ (20 km study, $r = 0.74$, $p < 0.05$, $n = 17$). These results are in agreement with the literature relating to distance running ($r = 0.97$, $p < 0.05$, $n = 18$, 15 km race, Farrell *et al.* 1979) and race walk performance specifically by Hagberg and Coyle (1983) ($r = 0.95$, $p < 0.05$, $n = 8$, 20 km race walk). The correlations between velocity at LTP and male athlete performance suggests that success in race walk competition over 20 km can be largely related to the ability to attain and sustain a high race walking speed without accumulation of B_{lac} , i.e. the energy contribution to ATP resynthesis is largely aerobic.

Blood lactate variables were also closely correlated with the female athletes $v\text{-20 km}$, in particular $v\text{-LTP}$ ($r = 0.62$, $p < 0.05$, $n = 12$). These results were in agreement with the literature relating to female 5 km cross country running performance by Berg *et al.* (1995) ($r = 0.83$, $p < 0.05$, $n = 7$, female

5 km cross country run) and female race walk competition performance by Yoshida *et al.* (1989) ($r = 0.85$, $p < 0.05$, $n = 8$, 5 km walk). Like the correlation between v-LTP in the male athletes, the female data suggested that success in 20 km race walk competitions could be largely related to the ability to attain and sustain a high race walking speed without accumulation of B_{lac} .

Aerobic energy contribution to the 20 race walk events

The average energy cost of the 20 km and performances by the male athletes in the present study according to Equation 1 by Arcelli (1996) was $51.6 \text{ ml O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$.

Equation 1. “race walking”

$$(6.86v - 38.8) = \text{average energy cost (ml O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1})$$

where v = velocity in $\text{km} \cdot \text{h}^{-1}$

The variables entered into the stepwise multiple linear regression analysis have been identified as central to performance speed in endurance athletes, including race walkers (Coyle, 1995; and Bassett and Howley, 2000). V-LTP explained a large segment of variance in race pace among the male athletes (53 %, Table 5a) and correlated with performance in female 20 km ($r = 0.62$, $p < 0.05$). In the present studies LTP was about $3.0 \text{ mmol} \cdot \text{l}^{-1}$ ($2.8 \pm 0.9 \text{ mmol} \cdot \text{l}^{-1}$, male athletes and $2.9 \pm 1.3 \text{ mmol} \cdot \text{l}^{-1}$, female athletes, Table 3), which may exemplify the uneven aerobic condition described by Antonutto and di Prampero (1995) in which lactate production and removal were equally increased demonstrating how whole body sources for muscular work could be entirely aerobic under steady state conditions despite a higher than resting B_{lac} level. They noted that peak glycogen oxidation rates are attained at the “uneven aerobic” exercise intensity, which occurred at LTP. Therefore the uneven aerobic condition may set not only the intensity of exercise, but also the capacity, as it may be responsible for an increased glycogen flux in the muscle fibres producing lactate (Antonutto and Di Prampero, 1995). The accumulation of B_{lac} can be attributed to either increased formation or decreased removal of lactate in the muscle, so at high exercise intensities demand for carbohydrate may result in an increased hydrogen concentration in the muscle, which could

have a negative impact on muscle function. Thus, there would be a rapid carbohydrate turnover and increasing acidosis in the muscle above exercise intensities associated with LTP, which would be inconsistent with being able to maintain a faster pace over the race distance (Bassett and Howley, 2000). The uneven aerobic condition may also be a demonstration of the lactate shuttle (Brooks, 1988) where lactate produced by active type II fibres could have reached muscle capillaries, proceeding into the general circulation, thus elevating B_{lac} , or may have reached adjacent type I fibres to be oxidised, i.e. supporting the findings of Donovan *et al.* (2000) where approximately 50 % of lactate removal in skeletal muscle could be accounted for by oxidation in type I and IIa fibres.

Fractional utilisation of VO_{2max} at LTP was about 88 % in the study (88 ± 4 % $mmol \cdot l^{-1}$, male athletes and 89 ± 8 % $mmol \cdot l^{-1}$, female athletes, Table 3) with the corresponding B_{lac} values of about $3.0 mmol \cdot l^{-1}$, possibly resulting from the combination of active muscle mass and the intensity of the muscle activation that was proposed by Billat (2003) to be factors in the appearance of lactate in the blood. Accordingly LTP in the race walkers in the present studies could have been affected by muscle fibre type, lactate transport across membranes (possibly involving MCT proteins in cell membranes (Brooks, 2000)), blood flow and blood distribution (Billat, 2003).

The relationship between LTP and muscle fibre type was studied by Ivy *et al.* (1980) who found a correlation of $r = 0.74$ ($p < 0.05$, $n = 9$ male) between LTP and percentage of type I muscle fibres during cycle ergometer exercise. Race walking above LTP would result in a different metabolic response compared with race walking at or below LTP, i.e. a higher rate of energy utilisation and increased levels of B_{lac} . Holloszy and Coyle (1984) found the rate of energy utilisation, where B_{lac} began to accumulate, was limited by skeletal muscle oxidative capacity and strongly influenced by training. Therefore it could be of value to investigate the influence of training on LTP in race walkers as this variable was the strongest correlate with performance in male athletes; and was correlated with female performance.

Two physiological variables combine in v-LTP according to Coyle (1995): the race walk VO_2 at LTP and the race walk speed that could be achieved at that VO_2 , described as submaximal economy. The VO_2 at LTP for an event

such as the 20 km race walk was shown to be closely related to the VO_2 that an athlete could sustain over the given duration of an event by Coyle (1995) and was described as a combination of $\text{VO}_{2\text{max}}$ and the fraction of $\text{VO}_{2\text{max}}$ that could be maintained during performance, e.g. 20 km race walk. Bassett and Howley (2000) noted fractional utilisation of $\text{VO}_{2\text{max}}$ was linked to changes in muscle oxidative capacity arising from chronic training stimulus as found by Holloszoy and Coyle (1984).

Race walking economy

There was no correlation between race walking economy ($\text{ml O}_2 \cdot \text{kg}^{-1} \cdot \text{km}^{-1}$ at $12 \text{ km} \cdot \text{h}^{-1}$) and performance in the study (male athletes, $r = -0.12$, $p > 0.05$, $n = 15$, female athletes, $r = -0.04$, $p > 0.05$, $n = 11$), which is in agreement with Yoshida *et al.* (1989), although these authors examined a different racing distance: 5 km. However Hagberg and Coyle (1983) did report that race walking economy in male athletes was significantly related to 20 km race pace ($r = -0.89$, $p < 0.05$, $n = 8$, economy identified by VO_2 values at $10 \text{ km} \cdot \text{h}^{-1}$) and concluded that submaximal economy appeared to be related more closely to performance in race walking than in running. In runners with a similar $\text{VO}_{2\text{max}}$ running economy is a good predictor of performance (Saunders *et al.* 2004) so the lack of correlation between race walking economy and performance (i.e. v-20 km) may reflect a heterogeneous athlete population in the present studies, contradicting the comment above about homogeneity and $\text{VO}_{2\text{max}}$.

The correlation between performance and VO_2 at LTP in the study was not uniform (male athletes, $r = 0.69$, $p < 0.05$, $n = 15$, female athletes, $r = -0.15$, $p > 0.05$, $n = 12$), e.g. only the correlation for the male athletes in the 20 km study was in agreement with the findings of Hagberg and Coyle (1983) who also reported a correlation in male 20 km athletes ($r = 0.82$, $p < 0.01$, $n = 8$), while Yoshida *et al.* (1989) found no correlation between race walking economy and v-5 km in female race walkers. Hagberg and Coyle (1983) noted that the VO_2 at LTP and the submaximal economy appeared to contribute to a different extent in the determination of v-LTP during running and race walking exercise modes, i.e. submaximal economy appeared to be more closely related to race walking performance than running performance, proposing that this was related to race walk biomechanics rather than energy metabolism. In the present study the fastest (athlete *a*) and fourth fastest (athlete *b*) male 20 km athletes were

identical in their VO_2 at LTP ($68.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), yet athlete *a* was walking 3.6 % faster in the race (20 km = 1 h 25 min 56 s v 1 h 28 min 34 s). Hagberg and Coyle (1983) found a difference of $0.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ between VO_2 at LTP in three male athletes but a variation in performance of 11 % and concluded the differences in v-20 km were not due to differing abilities to expend energy below LTP, but in submaximal economy, i.e. race walk speed at a given VO_2 . The difference in v-20 km between athlete *a* and athlete *b* and the probable impact of submaximal (or race walking) economy is shown in Figure 4.

The fraction of $\text{VO}_{2\text{max}}$ at LTP was $88 \pm 4 \%$ in the male athletes, which compares with trained marathon runners reported to utilise 94% of $\text{VO}_{2\text{max}}$ over 5 km and 82% over 42.2 km (Davies and Thompson, 1979) and between 80 and 85 % (Bassett and Howley, 2000) and 86 % over 42.2 km (Sjödín and Svedenhag, 1985). The 20 km is not walked at 100 % $\text{VO}_{2\text{max}}$, however ATP production is dependant on the VO_2 that can be maintained during the race. In the present studies this would be determined by the $\text{VO}_{2\text{max}}$ and the fraction of $\text{VO}_{2\text{max}}$ that the athlete could achieve. Arcelli (1996) calculated that to complete 20 km in World Record time (1 h 17 min 21 s) the athlete would have to maintain a VO_2 of $68.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ throughout the race. As a result, should it be possible to walk 20 km at 100 % $\text{VO}_{2\text{max}}$ the athlete would require a $\text{VO}_{2\text{max}}$ of $68.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ to race the distance in 1 h 17 min 21 s. In the present study v-LTP ($13.5 \pm 0.9 \text{ km}\cdot\text{h}^{-1}$) was slightly higher than v-20 km ($13.2 \pm 0.6 \text{ km}\cdot\text{h}^{-1}$), however the fraction of $\text{VO}_{2\text{max}}$ at LTP ($88 \pm 4 \%$) suggests a $\text{VO}_{2\text{max}}$ in the region of $77.0 - 82.0 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ would be required to race walk 20 km in World Record time.

The examination of fractional utilisation demonstrates how $\text{VO}_{2\text{max}}$ establishes the upper limit for performance in the 20 km race walk but does not resolve the outcome of competition (Figure 5), e.g. the highest $\text{VO}_{2\text{max}}$ value recorded in the study was $79.0 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ by an athlete who recorded 1 h 28 min 34 s in the 4 week time frame either side of his laboratory visit, compared to $73.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ recorded by the fastest 20 km athlete in the study whose time was 1 h 24 min 43 s. In the study the fraction of $\text{VO}_{2\text{max}}$ at LTP did not correlate with v-20 km ($r = -0.35$, $p > 0.05$, Table 4a), which is in agreement with studies of experienced

athletes who have prepared for marathon races with appropriate endurance training (Sjödín and Svedenhag, 1985). If the present study had included club level and recreational athletes to provide a larger variation in 20 km performance then fractional utilisation of $\text{VO}_{2\text{max}}$ may have provided a statistically significant correlation with v-20 km. In a study of male cyclists and triathletes ($n = 36$) Meyer *et al.* (1999) found a large variation between the fraction of $\text{VO}_{2\text{max}}$ and exercise intensities defined in relation to LTP. This led them to conclude that the percentage of $\text{VO}_{2\text{max}}$ was not suitable for determining exercise intensities alone and that B_{lac} measurements were preferable, e.g. in the present study the correlations between v-20 km and fractional utilisation of $\text{VO}_{2\text{max}}$ at LTP and v-LTP were $r = -0.35$, $p > 0.05$ and $r = 0.74$, $p < 0.05$ respectively (Table 4a).

The fraction of $\text{VO}_{2\text{max}}$ at LTP was $89 \pm 8\%$ for the female athletes in the study and did not correlate with v-20 km ($r = -0.29$, $p > 0.05$, Table 4b) or with $\text{VO}_{2\text{max}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) ($r = 0.17$, $p > 0.05$, Table 3.5b), which is similar to the findings of Rusko *et al.* (1980) who found no correlation between fraction of $\text{VO}_{2\text{max}}$ at LTP or $\text{VO}_{2\text{max}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) in female cross country skiers ($n = 15$). Rusko *et al.* (1986) found statistically significant correlations between VO_2 at LTP and citrate synthase ($r = 0.58$, $p < 0.05$, $n = 15$) and fraction of $\text{VO}_{2\text{max}}$ at LTP and succinate dehydrogenase ($r = 0.63$, $p < 0.05$, $n = 15$) from muscle biopsy samples taken from the vastus lateralis muscle, which led them to conclude that LTP seemed to be related to the oxidative capacity of muscle. Therefore in an investigation into the influence of training on LTP in race walkers an improvement in LTP may be explained by improvements in the oxidative capacity of the skeletal muscle.

Race walking economy, expressed as the energy required per unit of mass to race walk over a horizontal distance at $12.0\text{ km}\cdot\text{h}^{-1}$ ($\text{ml O}_2\cdot\text{kg}^{-1}\cdot\text{km}^{-1}$) did not correlate with v-20 km. However it is difficult to discount race walking economy as it may have contributed to the differences in v-20 km between athlete *a* and *b* who were identical in VO_2 at LTP (Figure 4). Likewise race walking economy may have interacted with $\text{VO}_{2\text{max}}$ to explain the differences in v- $\text{VO}_{2\text{max}}$ between athlete *d* and *e* who were identical in $\text{VO}_{2\text{max}}$ (Figure 6). This is similar to Daniels (1992) findings that different running economies resulted in a different v- $\text{VO}_{2\text{max}}$ in distance runners of equal $\text{VO}_{2\text{max}}$. Each athlete exhibits a linear relationship between race

walking speed and VO_2 , which interact to give $v\text{-VO}_{2\text{max}}$. As Figure 6 showed there was variation between each pair of athletes in how much oxygen it cost to race walk at given speeds, i.e. athlete *e* had the better race walking economy respectively resulting in the faster $v\text{-VO}_{2\text{max}}$. Differences between $v\text{-VO}_{2\text{max}}$ in athletes with virtually identical race walking economy may explain the differences in $\text{VO}_{2\text{max}}$ between athlete *e* and *f* (Figure 7), which also supports the findings of Daniels (1992) in his study of running economy. Moreover, Yoshida *et al.* (1990) found race walking economy improved 8.8 % from 43.5 ± 3.1 to $40.0 \pm 2.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ at $10.2 \text{ km}\cdot\text{h}^{-1}$ ($p < 0.05$, $n = 5$) following an eight week training intervention in competitive female race walkers resulting in a 6.8 % improvement in 5 km walk performance ($p > 0.05$). The authors drew a similar conclusion to Hagberg and Coyle (1983) that exercise economy was possibly a specific phenomenon for competitive race walkers compared to runners, alluding to race walking technique having a greater impact on variance in race walking performance than running technique on variance in running performance?

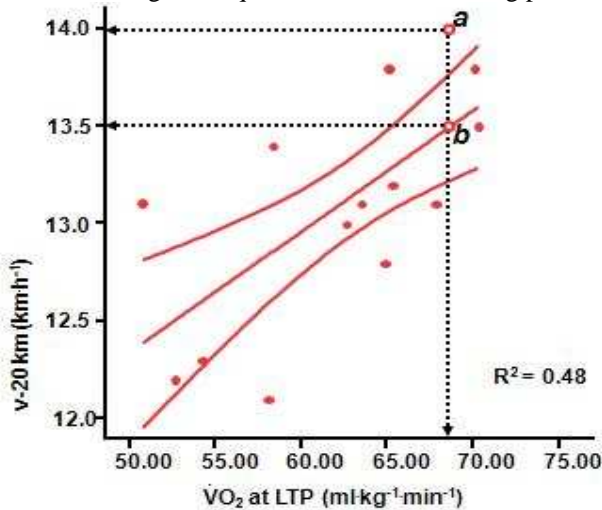


Fig. 4 Athletes *a* and *b* have identical VO_2 at LTP ($68.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). The v-20 km of athlete *a* was $14.0 \text{ km}\cdot\text{h}^{-1}$ v $13.5 \text{ km}\cdot\text{h}^{-1}$ for athlete *b*. The ability to expend energy before LTP is identical, therefore differences in v-20 km maybe explained by submaximal economy, i.e. race walk speed at a given VO_2 .

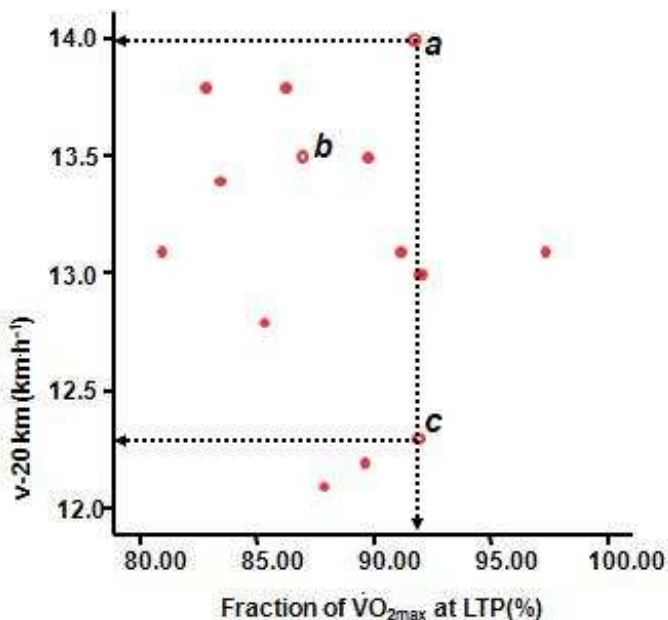


Fig. 5 Athletes *a* and *c* have identical fractional utilisation of VO_{2max} . The $v_{-20 km}$ of athlete *a* was $14.0 \text{ km} \cdot \text{h}^{-1}$ v $12.3 \text{ km} \cdot \text{h}^{-1}$ for athlete *c*. The examination of fractional utilisation demonstrates how VO_{2max} establishes the upper limit for performance in the 20 km race walk but does not resolve the outcome of competition. NB athlete *b* from Figure 4 is included for comparative purposes.

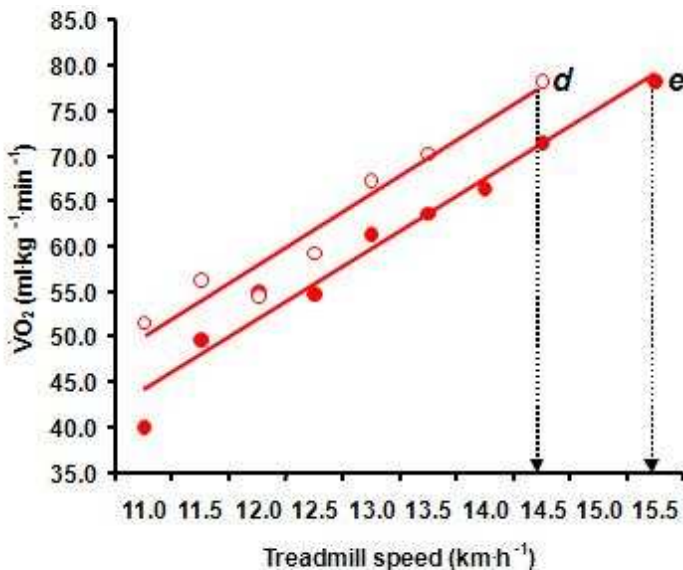


Figure 6. Athletes *d* and *e* have identical VO_{2max} . The $v-VO_{2max}$ of athlete *d* was $14.5 \text{ km}\cdot\text{h}^{-1}$ v $15.5 \text{ km}\cdot\text{h}^{-1}$ for athlete *e*. A line was drawn through the VO_2 data points to create a race walking economy line ending at the VO_{2max} of each athlete. A perpendicular line was dropped from the VO_{2max} value of each athlete to the x-axis to demonstrate the $v-VO_{2max}$. The data points used to construct the race walking economy lines for athletes *d* and *e* are lower at every point but there is a clear $1 \text{ km}\cdot\text{h}^{-1}$ difference in $v-VO_{2max}$ between the two, i.e. athlete *e* is more economical than athlete *d*.

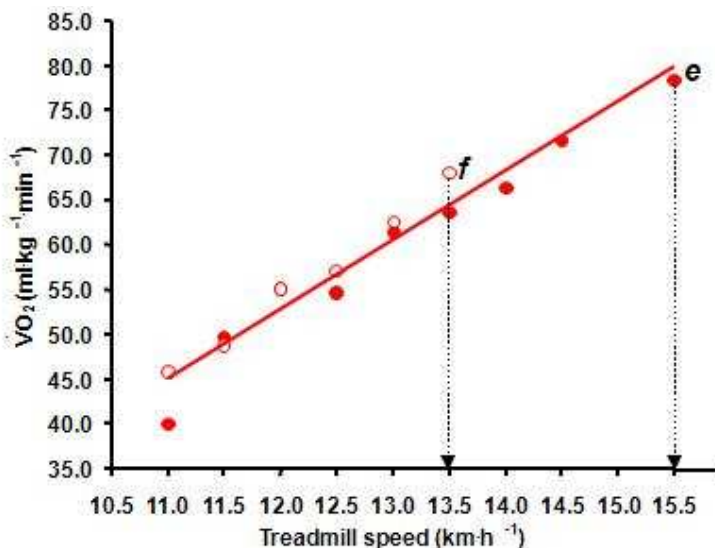


Figure 7. Athletes *e* and *f* have identical race walking economy. The $v\text{-VO}_{2\max}$ of athlete *f* was $13.5 \text{ km}\cdot\text{h}^{-1}$ v $15.5 \text{ km}\cdot\text{h}^{-1}$ for athlete *e*. A line was drawn through the VO_2 data points to create a common race walking economy line. A perpendicular line was dropped from the $\text{VO}_{2\max}$ value of each athlete to the x-axis to demonstrate the $v\text{-VO}_{2\max}$. The Figure demonstrates the influence of $\text{VO}_{2\max}$ on $v\text{-VO}_{2\max}$ in two athletes with virtually identical race walking economy.

Despite the lack of correlation between race walking economy and v-20 km in the present study, the examination of VO_2 at LTP, fractional utilisation of $\text{VO}_{2\text{max}}$ and differences in v- $\text{VO}_{2\text{max}}$ demonstrated the apparent impact of race walking economy in explaining some of the variation in v-20 km. The interrelationships between these variables are summarised in Figure 8.

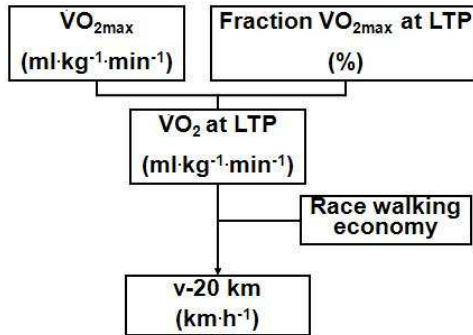


Figure 8. The relationships between $\text{VO}_{2\text{max}}$, the fraction of $\text{VO}_{2\text{max}}$ at LTP, the VO_2 at LTP, race walking economy and (e.g.) v-20 km (adapted from Bassett and Howley, 1999).

Conclusions

Correlations of descriptive data obtained during the discontinuous incremental treadmill race walk test to volitional exhaustion and v-20 km showed that among the variables analysed only v-LTP and v- $\text{VO}_{2\text{max}}$ had statistically significant correlations ($p < 0.05$) in both male and female data analysis. $\text{VO}_{2\text{max}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) was only significantly correlated ($p < 0.05$) with v-20 km in male athletes, however v- $\text{VO}_{2\text{max}}$ is strongly affected by race walking economy and $\text{VO}_{2\text{max}}$ (Bassett and Howley, 1999; Coyle, 1995; Daniels and Daniels, 1992; Morgan *et al.* 1989) so it may be unwise to dismiss the importance of $\text{VO}_{2\text{max}}$ in the other athletes. $\text{VO}_{2\text{max}}$ has been found to increase by about 20 % in athletes following endurance training, highlighting the large genetic component to this measure (Bouchard *et al.* 1999), whereas muscle oxidative capacity has been found to increase by between 40 and 100 % (Holloszoy and Coyle, 1984) suggesting variables such as v-LTP are trainable, as is v- $\text{VO}_{2\text{max}}$ (Daniels, 1992; Billat *et al.* 1999), largely via its economy component. The efficacy of investigating the training response in v-LTP and v- $\text{VO}_{2\text{max}}$ to race walking training is worthy of research; moreover the role of race walking biomechanics in variance in

race walking economy warrants investigation despite no correlations between race walking performance and economy *per se* in the present studies.

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PREDICTION OF RACE WALKING PERFORMANCE VIA LABORATORY AND FIELD TESTS

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Abstract

The present study supports the use of a field based 2 km race walking time trial as a predictor of velocity at maximum oxygen uptake in athletes competing in race walking events. Moreover the 2 km time trial provides a useful link between laboratory and performance variables in the construct of the race walking nomogram, which is an easy to use coaching tool for athletes and coaches.

Key words: Race Walking; Performance Prediction; Oxygen Uptake; Testing; Monitoring.

Problem

Athletes compete in race walking events of 3-10 km and the Olympic distances 20 km and 50 km. Previous studies of race walking events (Drake *et al.* 2003; Hagberg & Coyle, 1983; Yoshida *et al.* 1989) each concluded that success in these events was probably related to the ability to attain and sustain a high race walking velocity without accumulation of blood lactate (B_{lac}). It may be useful to be able to predict performance if the relationships between standard race velocities and different physiological variables are known. However it may be impractical to perform a laboratory test, yet could be efficacious to predict race walking performance and/or physiological variables (e.g. maximum oxygen uptake (VO_{2max})) from performances in other distances and/or a field based test such as a time trial. For example Mercier *et al.* (1986) developed a nomogram to predict performance equivalence for distance runners; and Billat *et al.* (1994) and Berthon *et al.* (1997) developed field based tests to calculate velocity at maximum oxygen uptake ($v-VO_{2max}$). Dabonville *et al.* (2003) found that the 5 min running test of Berthon *et al.* (1997) was a reliable field test for estimating $v-VO_{2max}$ from only one trial. Billat *et al.* (1994) found that the duration of running performance that could be maintained at $v-VO_{2max}$ was 5 min 21 s \pm 1 min 23 s. Berthon *et al.* (1997) found running $v-VO_{2max}$

correlated best with performance over 3 km, which varied from 8 min 08 s to 15 min 36 s ($r = 0.97$, $p < 0.05$, $n = 9$ male runners); and Daniels (1998) described $v\text{-VO}_{2\text{max}}$ as representative of the speed of a running race lasting between 10 to 15 min, therefore a 2 km race walk would compare with a 3 km run performance time wise. Moreover laboratory-, performance- and field-based variables could be combined to construct the interrelationships between them, e.g. to create a nomogram to predict $\text{VO}_{2\text{max}}$, $v\text{-VO}_{2\text{max}}$, 2 km time trial performance and 3 km, 5 km, 10 km, 20 km and 50 km race walk performance if one or more of the values was known.

Aim

Therefore the purpose of this study was to develop a nomogram to predict performance equivalence for race walking, which would enable coaches and athletes to predict performance and/or physiological variables (e.g. $\text{VO}_{2\text{max}}$) from performances in other distances and/or a field based test such as a time trial.

Methodology

Forty-five male and twenty-three female race walkers participated in this study, which had University ethical approval. The mean age, height, body mass and maximum oxygen uptake was 27 ± 8 y; 1.73 ± 0.08 m; 64.3 ± 9.8 kg; and 62.9 ± 11.3 ml·kg⁻¹·min⁻¹.

The athletes completed between six and nine 4-minute stages of race walking on a motorised treadmill. All tests began at a 1% gradient, increasing by 0.5 km·h⁻¹ each stage, with a starting speed 2.0 km·h⁻¹ below the current race speed for 10 km of the subject. On completion of each stage a 20 µl arterialed capillary blood sample was obtained from the ear lobe for the determination of blood lactate (B_{lac}) values used to identify lactate turnpoint (LTP). Expired air was collected into a Douglas bag for the last 60 s of each stage to determine oxygen uptake (VO_2) and race walking economy (ml O₂·kg⁻¹·km⁻¹). When heart rate (HR) exceeded 95 % of the predicted maximum or B_{lac} exceeded 4 mmol·l⁻¹ the treadmill gradient was increased by 1% every 60 s. The test continued until volitional exhaustion for the determination of maximum oxygen uptake ($\text{VO}_{2\text{max}}$). The velocity at lactate turnpoint ($v\text{-LTP}$) was the race walking speed at which there was an abrupt and exponential increase in B_{lac} values. The velocity at $\text{VO}_{2\text{max}}$ ($v\text{-VO}_{2\text{max}}$) was resolved by linear regression on sub-maximal race walking speed and VO_2 values.

Thirteen male and eight female race walkers from the main subject group (above) also race walked an all out 2 km time trial on a 400 m Mondo surface athletics track for calculation of v-2 km ($\text{km}\cdot\text{h}^{-1}$). The time trial was undertaken within 24 hours of completing the discontinuous incremental treadmill test described above. Subjects were informed they should race walk as fast as possible and to treat the time trial as a race effort. Time trials began after subjects had completed a 20-minute warm up. Tests were undertaken on windless days when the track was dry. Subjects completed their time trials alone on the track to avoid creating a competitive environment on occasions when two or more were to participate. The mean \pm SD age, height, body mass and $\text{VO}_{2\text{max}}$ of the 2 km time trial group was 22 ± 9 y; 1.75 ± 0.07 m; 62.3 ± 9.1 kg; and 55.6 ± 8.9 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. V-2 km was compared to v- $\text{VO}_{2\text{max}}$ identified in the laboratory and race walk performances over 3 km, 5 km, 10 km, 20 km and 50 km by the athletes taking part in the present studies. Moreover race walk performances over 3 km, 5 km, 10 km, 20 km and 50 km attained by athletes ranked in the World, British or Italian top 50 between 1999 and 2003 were combined to create a nomogram to predict $\text{VO}_{2\text{max}}$, v- $\text{VO}_{2\text{max}}$, 2 km time trial performance and 3 km, 5 km, 10 km, 20 km and 50 km race walk performance if one or more of the values was known.

Outcomes

The 2 km time trial performance time was 554 ± 65 s. v-2 km was compared to v- $\text{VO}_{2\text{max}}$ and race walk competition performances over 3 km, 5 km, 10 km, 20 km and 50 km recorded within four weeks pre- or post-laboratory test. v-2 km (13.2 ± 1.6 $\text{km}\cdot\text{h}^{-1}$) was 0.2 % higher than v- $\text{VO}_{2\text{max}}$ (13.1 ± 1.5 $\text{km}\cdot\text{h}^{-1}$) ($p > 0.05$); and 10.9 % higher than v-LTP (11.7 ± 0.7 $\text{km}\cdot\text{h}^{-1}$) ($p < 0.05$). v- $\text{VO}_{2\text{max}}$ accounted for 94 % of the variance in 2 km time trial performance when analysed by multiple stepwise linear regression. The relationship between v- $\text{VO}_{2\text{max}}$ and v-2 km was resolved by following the “field-laboratory” equation in Table 1 ($R^2 = 0.96$, $n = 21$). To test whether the distribution of the $\text{VO}_{2\text{max}}$, v- $\text{VO}_{2\text{max}}$ and v-2 km data measured were significantly different from the normal distribution a Kolmogorov-Smirnov test (D) was used (Field, 2005). The distribution of the $\text{VO}_{2\text{max}}$ values, ($D(21) = 0.12$ ($p > 0.05$)), v- $\text{VO}_{2\text{max}}$ values ($D(21) = 0.21$ ($p > 0.05$)) and v-2 km values ($D(21) = 0.16$ ($p > 0.05$)) indicated a normal distribution.

Moreover data from the present study was combined to resolve the relationship between race walking speed and VO_2 , i.e. “common race

walking economy” (Table 1, $R^2 = 0.996$, $n = 68$); and the “performance-field” based relationship between v-2 km and v-3 km was resolved from race performances completed by the athletes who completed the 2 km time trial (Table 1, $R^2 = 0.76$, $n = 21$). The model construct was completed from analysis of 182 paired race walk times of athletes over the distances 3 km, 5 km, 10 km, 20 km and 50 km (Table 1). The construct from the interrelationship between laboratory-, performance- and field-based variables was the nomogram (Figure 1) that could be used to predict performance in race walking events and VO_{2max} .

Table 1. Relationships between paired race distances analysed using linear regression, where 3 km, 5 km, 10 km, 20 km and 50 km = hh:mm:ss. Predictive equations were established from World, British and Italian top 50 ranked performances 1999 – 2003, which were not significantly different ($p > 0.05$) from the present study. #linear regression not performed due to $n = 2$.

Field-laboratory	
v-2 km ($\text{km}\cdot\text{h}^{-1}$) = 1.1042 v- VO_{2max} ($\text{km}\cdot\text{h}^{-1}$) - 1.4011. $r = 0.96^*$, $R^2 = 0.96$, $n = 21$	
Common race walking economy	
VO_2 ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) = 5.2482 treadmill speed ($\text{km}\cdot\text{h}^{-1}$) - 12.334. $r = 0.85^*$, $R^2 = 0.996$, $n = 68$	
Performance-field	
v-3 km ($\text{km}\cdot\text{h}^{-1}$) = 0.8624 v-2 km ($\text{km}\cdot\text{h}^{-1}$) + 1.6626. $r = 0.93^*$, $R^2 = 0.76$, $n = 21$	
Paired race distances (h:mm:ss) used to construct nomogram	
3 km-5 km	5 km-10 km
5 km = 1.4468 3 km + 0.0024. $R^2 = 0.90$, $n = 31$	10 km = 2.0906 5 km - 0.0002. $R^2 = 0.92$, $n = 44$
10 km-20 km	20 km-50 km
20 km = 2.1031 10 km - 0.0009. $R^2 = 0.87$, $n = 44$	50 km = 2.8868 20 km - 0.0039. $R^2 = 0.74$, $n = 63$
Paired race distances (h:mm:ss) from present study for comparison	
3 km-5 km	5 km-10 km
5 km = 1.463 3 km + 0.0025. $R^2 = 0.82$, $n = 30$	10 km = 1.8573 5 km + 0.0034. $R^2 = 0.87$, $n = 34$
10 km-20 km	20 km-50 km
20 km = 2.2811 10 km - 0.0064. $R^2 = 0.86$, $n = 28$	$n = 2^{\#}$

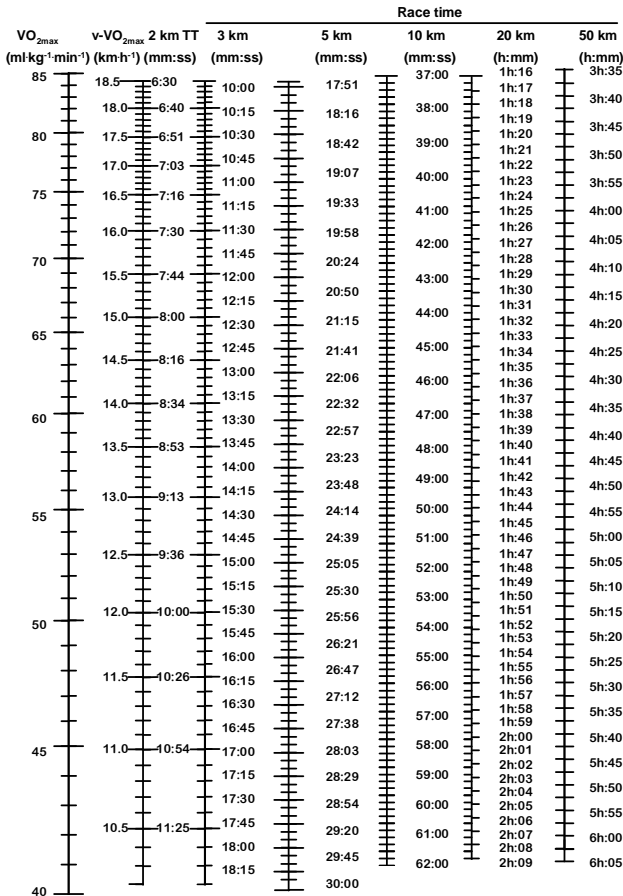


Figure 1. Nomogram to predict race walking performance at distances from 2 km to 50 km. VO_{2max} is predicted by passing a horizontal line through the 2 km time trial (TT) performance. The line that describes the race walking performance of an athlete at two distances allows prediction of performance at a third distance.

The linear regression equations from Table 1 predict small differences in performance. For example the VO_{2max} of the male athletes who completed a 2 km time trial was $55.6 \pm 8.9 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ with a corresponding $v-VO_{2max}$

of $13.2 \pm 1.6 \text{ km}\cdot\text{h}^{-1}$, equating to v-2 km of $13.2 \text{ km}\cdot\text{h}^{-1}$ (“field-laboratory” equation, Table 1) that is used to compute 3 km performance from 2 km time (“performance-field” equation, Table 1), i.e. v-3 km of $13.02 \text{ km}\cdot\text{h}^{-1}$. The linear regression equations from Table 1 predict a 1.6 % difference between 5 km performances (22 min 26 s derived from ranking data v 22 min 47 s derived from present study); a 1.3 % difference between 10 km performances (46 min 37 s derived from ranking data v 47 min 13 s derived from present study); and a 1.8 % difference between 20 km performances (1 h 36 min 44 s derived from ranking data v 1 h 38 min 30 s derived from present study). The relationships between paired performances from the present study compared to the ranking data are shown in Figure 2.

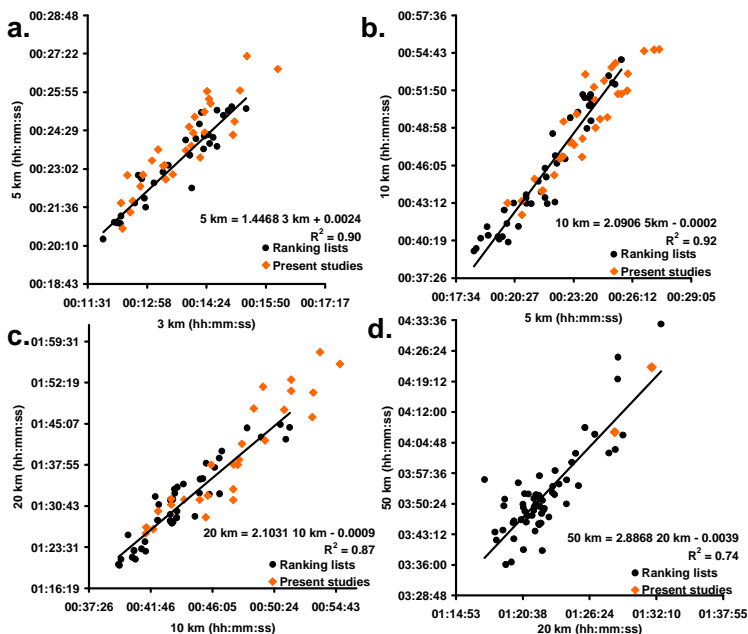


Figure 2. Relationships between paired performances from the present study compared to the ranking data used (a. 3 km – 5 km; b. 5 km – 10 km; c. 10 km – 20 km; and d. 20 km – 50 km). Performances by athletes ranked in the World, British or Italian top 50 between 1999 and 2003 were used to construct the model ($n = 56$ male, 37 female) (www.iaaf.org; www.ukathletics.org.uk; and www.fidal.it).

Conclusion

Certain assumptions were inherent in the construct of the nomogram, e.g. the relationship between race walking speed ($\text{km}\cdot\text{h}^{-1}$) and VO_2 ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). The regression equation created a curve that assumes common race walking economy; however the common curve ignores the differences in economy and the differences in $\text{VO}_{2\text{max}}$. In the race walking nomogram an athlete completing a 2 km time trial in 8 min 00 s would be predicted as having a $v\text{-VO}_{2\text{max}}$ of $15.0 \text{ km}\cdot\text{h}^{-1}$ and a $\text{VO}_{2\text{max}}$ of about $66.0 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, however in reality a $v\text{-VO}_{2\text{max}}$ of $15.0 \text{ km}\cdot\text{h}^{-1}$ may be attained by an athlete with a lower $\text{VO}_{2\text{max}}$ but superior race walking economy or by an athlete with a higher $\text{VO}_{2\text{max}}$ but inferior race walking economy, i.e. a race walker using the nomogram to predict $\text{VO}_{2\text{max}}$ may find a different value predicted to that which could be measured completing the discontinuous incremental treadmill race walking protocol.

Mercier *et al.* (1986) developed a nomogram to predict performance equivalence for distance runners and proposed a number of uses for such a tool, which are also applicable to the nomogram presented here. Race walk performance may be predicted by interpolation or extrapolation, e.g. an athlete completing a 2 km time trial in 8 min 00 s and 10 km in 44 min 06 s would be predicted to race walk 5 km in 21 min 14 s; the performances of an athlete completing a 2 km time trial in 7 min 21 s and 10 km in 41 min 04 s could be extrapolated to predict to 50 km in 3 h 59 min 58 s. A further use for the nomogram could be to determine the prerequisites to achieve a certain level of performance, such as a qualifying time, e.g. the “A” standard qualifying time for the 2008 Olympic Games Men’s 20 km was 1 h 23 min 00 s: an athlete seeking to attain this level of performance would have had to be able to complete a 2 km time trial in 7 min 08 s, 3 km in 10 min 57 s, 5 km in 19 min 18 s, or 10 km in 40 min 03 s.

In previous studies (Drake *et al.* 2003; Hagberg & Coyle, 1983; Yoshida *et al.* 1989) the relationships between several physiological variables and athlete performance suggested that success in race walk competition was largely related to aerobic endurance, i.e. the ability to attain and sustain a high race walking velocity for a long period of time. However the present study did not establish the validity of the laboratory based methods compared to the field based 2 km time trial to determine the relative

importance of the different variables in performance prediction, e.g. laboratory based threshold values v time trial performance.

The 2 km time trial provided information on $v\text{-VO}_{2\text{max}}$: $v\text{-2 km}$ and $v\text{-VO}_{2\text{max}}$ were not statistically significantly different from each other ($p > 0.05$) and $r = 0.98$ ($p < 0.05$). Furthermore the 2 km time trial and nomogram could be used for $\text{VO}_{2\text{max}}$ evaluation and to identify prerequisite levels of performance required to achieve goals such as attaining championship qualifying times. Even so the 2 km time trial warrants validation with more subjects to strengthen the interrelationships with laboratory- and performance-based variables.

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THE TRAINING FOR THE 20-km. WHAT HAS CHANGED AND WHAT MIGHT CHANGE?

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Abstract

In this section we reviewed the most topical results concerning the physiological adaptations of different training methods for the endurance disciplines that, in our opinion, might be useful for the race walk training as well, referring to practical experiences through the years. This is because, in our opinion, there is an insufficient direct scientific evidence to formulate training recommendations useful both for the race walk athletes and coaches. This is particularly evident when considering the many methodological factors associated with this discipline that matches the common physiological determinants of long-distance performance with the technical and regulations aspects. This doesn't mean that the scientific literature cannot provide valid support to enhance the performance in the race walk, but just that there is a lack of specific knowledge. Consequently, the ability of the coaches should be to shift the main findings of the research into the race walk training.

Key words: Athlete; Endurance; Training; Exercise Performance; Race Walk

Problem

Analysing the 20-km race walking (RW) performances in the last ten years, the number of athletes faster than 1 h 21 min 00 s and 1 h 31 min 00 s (for men and women, respectively) has grown-up. This means that there are more athletes at high-level and a possible explanation for this trend is a tendency towards a high training specificity. As already well-elucidated in this book, over its centuries-old history the physiological stress, energy expenditure or physiological determinants, which are important for RW performances, have been extensively investigated (Brisswalter et al., 1996; Brisswalter et al., 1998; Farley, Hamley, 1978; Hagreg, Coyle, 1983;

Reilly et al., 1979; Yoshida et al., 1988). Concerning the 20-km RW, to the best of our knowledge there are insufficient direct scientific evidences to formulate training recommendations useful for the coaches and athletes alike. This is particularly evident when considering the many methodological factors associated with the RW that matches the technical and regulation aspects with the common physiological determinants of long-distance performance: (i) maximal oxygen uptake ($\dot{V}O_{2\max}$) (Asmussen, 1993; Noakes, Myburgh, Schall, 1990); (ii) lactate threshold (LT) (Noakes et al., 1990; Tanaka, Matsuura, 1984); (iii) energy cost (EC) (Asmussen, 1993; Conley, Krahenbuhl, 1980; Noakes et al., 1990) and (iv) percent of maximum oxygen uptake ($\% \dot{V}O_{2\max}$) (Asmussen, 1993). Therefore, there is a lack of specific knowledge and the ability of the coaches should be to shift the main findings of the scientific literature inside the RW training, fusing the practical experiences with the theoretical knowledge.

Aim

The purpose of this section is to analyse the most topical results concerning the physiological adaptations of different training methods for the endurance disciplines (i.e. evidence-based coaching) that, on our opinion, might be useful for the 20-km training as well, refereeing to the practical experiences throughout the years.

Methodology

The development of sport performance can be achieved through a training process designed to induce automation of motor skills and enhance structural and metabolic functions (Smith, 2003). However, the training programmes required to reach these goals are usually somewhat intuitive, resulting from years of the coaches' personal experiences (Borresen, Lambert, 2009). Recently, a new science-based approach in search of optimal training has been developed in order to guide the practice of sport to improve sporting performances (Bishop, 2008). Consequently, the function of scientific research in this process is becoming more important, playing a key-role to allow coaches to set up valid training protocols to the athletes. Despite this increased interest of the sport sciences particularly among the endurance disciplines, no study has been conduct with regards to

RW. Therefore, as stated in the ‘problem’ section a lack of specific knowledge is occurring and RW coaches have to face to this evidences shortage transferring the general results coming out from the scientific studies in the RW training process.

Mainly, on our opinion this lack of specificity is basically to seek in three different areas:

- (i) the relationship between the volume and the intensity;
- (ii) the utilization of the combined strength-endurance training;
- (iii) the training load monitoring.

In the next sections we will discuss the aforementioned areas individually.

The relationship between the volume and the intensity

It is widely agree that the volume represents the global quantity of the training (i.e. the combination of duration and frequency) performed per week, month or year; while, the intensity is a qualitative component having a direct function on the activities performed in a given unit per time (Smith, 2003). Nowadays, the dynamics of training involve the manipulation of the above mentioned variables and the great debate inside the training methodology concerns the correct match of them inside the training process because the intensity and the volume of exercise all contribute to the nature and magnitude of the training effect (Birresen, Lambert, 2009).

Consequently, optimal training adaptation will take place if the degree of the TL (i.e. the combination of the intensity and the volume) is applied to a high-performance athlete in an appropriately sequenced manner. To date, one of the main question is if the athletes have to train themselves to an useful intensity or use greater part of their training time at low intensity.

It has been found that in sub-elite athletes ($\dot{V}O_{2max}$ around $70 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) the 68% of training is developed to an intensity lower than the ventilatory threshold and this has a strong correlations to the performances (Esteve-Lanao et al., 2005; Esteve-Lanao et al., 2007; Seiler, Kjerland, 2006); but, considering the adaptations that occur after the training, the result is that the training at low intensity improves only the aerobic parameters in sedentary

and/or less trained people (Laursen, Jenkins, 2002). In several recent studies it has emerged that only through high-intensities training (HIT) it is possible to get significant adaptations in high-trained athletes (Denadai et al., 2006; Duffield et al., 2006; Helgerud et al., 2007; O'Brien et al., 2008; Rozenek et al., 2007). Using also the sprint training (e.g. sprint 5/10 s with a recovery of 20/30 s) it is seen that it is possible to get a significant increase of the maximum oxygen uptake, despite the total volume of the training is lower (Dawson, Fitzsimons, Green, Goodman, Carey, Cole, 1998) Furthermore, speed endurance training can maintain muscle oxidative capacity, capillarisation and endurance performance in already trained individuals (Iaia et al., 2009) and the performance during intense exercise can be improved and endurance performance maintained even with a reduction in training volume if the intensity of training is very high (Iaia et al., 2008). Moreover, a study published by Burgomaster and colleagues suggests that HIT is a time-efficient strategy to increase skeletal muscle oxidative capacity and induce specific metabolic adaptations during exercise that are comparable to traditional endurance training (Burgomaster et al., 2005). Thus, the main findings of these studies are that the volume is very important for the training, but, above all, it is more important how many times the athlete is able to sustain an high intensity during his training. Therefore, it seems that nowadays there is a tendency to stop the explosion of the volumes to drive the training towards a specific intensity.

Despite in the endurance disciplines there is a tendency towards an improvement of the performances, in the RW this trend is not so strong (to have an insight into the performances above mentioned see the annual top-lists on the IAAF web site: <http://iaaf.org>); the reason might be attributed to the intrinsic limitations of the discipline (i.e. technical aspects). These represent the most important difference between running and RW, and may influence and limit the performance of the latter. Thus, it might be impossible for a race walker compete without a correct technical action. On our opinion, the main focus in the training for the 20-km RW should be orientated to how much of specific training the race walker is able to perform compared to his opponents without a loss in the technical gesture. On our opinion, this is an important concept because despite the importance of the technical training performed at low intensity, to train the specific technical gesture at the same (or higher) race-intensity can be considered a valid tool in order to accustom the athletes to perform a correct gesture (see IAAF rule 230) in a race settings.

According to Larsen and Jerkins, HIT can be defined as ‘a repeated bouts of short to moderate duration exercise (i.e. 10 s to 5 min) completed at an intensity that is greater than the anaerobic threshold’ (Laursen, Jenkins, 2002). Exercise bouts are usually separated by brief periods of low-intensity work or inactivity (i.e. using of intervals) that allow a partial but often not a full recovery. Thus, the purpose of HIT is to repeatedly stress the physiological systems used during a specific endurance discipline greater than that which is required during that type of activity (Daniels, Scardina, 1984).

BOX 1**Practical applications**

What does it means to train at HIT? A practical applications of what stated can be the employment of the race rhythm (RR) as referee mark (authors’ personal communications).

Example 1 – RR: 3 min 59 s. 10 x 1000 m (recovery: 1 min).

1. 3 min 55 s
2. 3 min 54 s
3. 3 min 50 s
4. 3 min 49 s
5. 3 min 46 s
6. 3 min 50 s
7. 3 min 44 s
8. 3 min 48 s
9. 3 min 47 s
10. 3 min 41 s

The athlete sustained the effort from 5 to 20 s faster than his RR (average of 3 min 48 s \pm 4 s).

Example 2 – RR: 3 min 59 s. 4 x 1000 m + 4 x 2000 (recovery of 1’ 1000 \rightarrow 2000 and 2’ 2000 \rightarrow 1000).

1. 3 min 57 s (7 min 55 s)
2. 3 min 50 s (7 min 50 s)
3. 3 min 45 s (7 min 46 s)
4. 3 min 38 s (7 min 40 s)

The athlete sustained the effort from 3 to 22 seconds faster than his RR, both for the 1000 m and 2000m.

Consequently, the volume is an important tool during the training sessions, but on our opinion it should be more important how much time the athlete sustains his training at an high intensity (more considerable information are

available on the ref. 35). However, if the interest around HIT is increasing, more knowledge regarding HIT programme optimisation are necessary, especially in the way to understand: (i) the intensity, (ii) the duration, and (iii) the recovery.

The utilization of the combined strength-endurance training

The physiological determinants of long-distance performance cited in the 'problem' section explain > 70% of the between-subject variance (di Prampero et al., 1986). Factors related to the muscular power (e.g. neuromuscular and anaerobic aspects) have been added because it seems that they could limit the endurance performance (Houmard et al., 1991; Noakes, 2000; Sinnett et al., 2001). The reduction of the muscular tension and the ability to express the strength, besides the difficulty to increase the intensity at the end of a competitions, are specific features of the fatigue behaves (Asmussen, 1993; Hunter et al. 2004; Leppik et al., 2004; Lewis, Fulco, 1998). This means that the damages led to the muscular action may be partly responsible of the performance decrease because they might alter the muscle characteristics or the perceived exertion even when the 'system' is in a good conditions (Marcora, Bosio, 2007; Scott, Binder-Macleod, 2003). The literature has analyzed different types of strength and the mix of them (Hoff et al., 2002; Paavolainen et al., 1999), but the general conclusion is that the neuromuscular aspects are more important than the hypertrophy in the endurance disciplines and, in the same training session, it is better to carry out the endurance training before the strength training without a decrease in the physiological determinants of long-distance performance in high-level athletes (Hoff et al., 2002; Mikkola et al., 2007; Paavolainen et al., 1999; Sauders et al., 2006).

The possible introduction of the strength training in the RW seems to have some positives effects, increasing the specific strength; the walking economy (WE); and the time to exhaustion. This because there is the necessity to improve all the aspects of the RW performance and also to face to the tactical necessities of the competitions and, moreover, to oppose the fatigue-related neuromuscular aspects that for RW are not only related to the physiological aspects but, also, to the technical ones. As an example during the Olympic Games in Beijing 2008, during the 20-km RW men, there was a sudden change of the rhythm; the athletes covered 2-km in a pace of 7 min 50 s (which means a pace of 3 min 55 s · km⁻¹) and the next

one in 7 min 20 s ($3 \text{ min } 40 \text{ s} \cdot \text{km}^{-1}$); a variation of 30 s and $1 \text{ km} \cdot \text{h}^{-1}$ in the rhythm and speed (from $15.3 \text{ km} \cdot \text{h}^{-1}$ to $16.3 \text{ km} \cdot \text{h}^{-1}$), respectively. On our opinion this is possible only if the athletes are also able to sustain very high loads that require the development of an high muscular component.

Consequently, on our opinion the muscular power-related factors are becoming more important for endurance disciplines (i.e. also including strength training in the overall periodisation), because:

- (i) there is the necessity to improve all the aspects of the performance;
- (ii) to face to the tactical necessities of the competitions;
- (iii) nowadays, fights at the conclusive phases of the races are increasing;
- (iv) to oppose the fatigue-related neuromuscular aspects.
- (v) to enforce and to complete the technical training.

BOX 2

Practical applications

Our personal experiences through the years led us to introduce even the strength inside RW training, always following the guide lines suggested by the scientific literature.

Example 1 – The adaptations monitoring of a combined strength and endurance program in two female race walkers have been conducted (authors' personal communication). The athletes were examined before and after 12 weeks of strength (i.e. circuit resistance training) and endurance training, performing an incremental field test for the maximum oxygen uptake, WE and lactate threshold (LT), and the results showed that this kind of training led to a significant increase in the LT and the 5000 meters performance, without changes in the $\dot{V}O_{2 \text{ max}}$ and WE.

Thus, the introduction of the strength training in the RW periodisation seems to have several positive effects in different areas, as: (i) strength, (ii) LT, and (iii) time to exhaustion, but these modifications not involve the aerobic parameters already reached by the athletes. Furthermore WE was not affected by these type of training (in contrast to what stated above) and a possible explanation for this result is that this training period (i.e. 12 weeks) is too small to allow significant modifications in the athletes' WE.

The training load monitoring

If the main goal of coaches and athletes is to produce the best performance at a specific time (preferably during the main competition), the training process should take into account also the monitoring of the athlete's training status during the season. Thus, more attention has to be directed towards measurements that reflect individual capacity to respond to specific training rather than an absolute measure of changes that occur with it (Borresen, Lambert, 2009). Despite the extremely difficult to measure and quantify all input factors affecting an athlete during his own training process the comprehensive monitoring of exercise intensity and training load (TL) during training phases can provide important feedback to the coaches regarding the training stimulus applied to the athletes (Coultts et al., 2007). Consequently, the common way to monitoring the training (i.e. using the training volume which is the product between duration and frequency) is no more enough.

Nowadays, there have been several non-invasive attempts to quantify the exercise intensity such as: (i) heart rate monitoring (HR) (Achten, Keukendrup, 2003; American College of Sports Medicine Position Stand, 1998), and (ii) rate of perceived exertion (RPE) (Borg, 1998; Borg, 1982). The former can be used to give useful information on the internal load experienced by the athlete (always referred in a relative – e.g. % HR_{max} – rather than an absolute manner), while the latter provides an alternatively valid and time effective method to quantify the overall exercise intensity. However, as already stated in the 'the relationship between the volume and the intensity' section, intensity referred to a qualitative variable in an unit of time (e.g. a bout); thus, both coaches and athletes have the necessity to organise the training taking into account the following elements: (i) intensity, (ii) duration, and (iii) frequency. TL is a combination of the aforementioned variables. Methods for objectively quantifying the HR-based TL has been developed by several authors (Banister, 1991; Edwards, 1993; Lucia et al., 2003) and for a full review we remind to Borresen and Lambert (Borresen, Lambert, 2009). Using RPE, an alternative strategy to quantify TL was proposed by Foster et al. (Foster et al., 1995; Foster, 1998; Foster et al., 2001). This method (aka session-RPE) quantifies TL multiplying the whole training session RPE (using the category ratio scale - CR10 scale® (Borg, 1982) by its duration. This product represents in a

single number the magnitude of internal TL in arbitrary units (AU) (Impellizzeri et al., 2004).

Thus, in order to verify the TL during a RW training and/or performance, the ability to match the information deriving from the training volume and the TL may be critical for training periodisation process.

BOX 3

Practical applications

Example 1 – To date, HR is easy to monitor, is relatively cheap and can be used in most situations, both during training or race. For example, the Edwards' method (20) determines TL by measuring the product of the accumulated training duration (minutes) of 5 HR zones by a coefficient relative to each zone (50–60% of HR_{max} = 1; 60–70% of HR_{max} = 2; 70–80% of HR_{max} = 3; 80–90% of HR_{max} = 4; 90–100% of HR_{max} = 5) and then summing the results. Consequently, an TL evaluation has been conducted on an athlete during a 5-km RW indoor race (authors' personal communication). Starting from his HR_{max} (192 beats·min⁻¹) and race time (18 min 23 s 47 tenths) he spent: 15 s at 50–60% of HR_{max} ; 15 s at 60–70% of HR_{max} ; 20 s at 70–80% of HR_{max} ; 35 s at 80–90% of HR_{max} ; 17 min at 90–100% of HR_{max} . The result shows that his TL was 89.06; consequently, this result can be considered a TL reference for that kind of effort and than can be compared with other TL obtained with the same method on the same distance.

Example 2 – The session-RPE cited above can be considered a valid method of quantitating exercise training during a wide variety of type of exercises in RW. For example, during a 10000-m race walk competition session-RPE (Foster et al., 1995; Foster, 1998; Foster et al., 2001) was asses on 14 male race walkers who performed a 10000-m competition on a certified 400 m outdoor-tartan-track (authors' personal communication). The RPE scale was in full view of the participants, using two A1 international standard (ISO 216) paper formats (594 · 841 mm), placed in correspondence of every 1000-m. 50-m before each 1000-m an operator recalled to the participants to report the sensation of exertion to another operator positioned at the paper format. The mean TL for the entire race was 602.21, while the mean TL for each 1000-m was:

1. 50.22
2. 53.28

3. 58.35
4. 59.94
5. 61.70
6. 63.46
7. 63.77
8. 66.30
9. 68.99
10. 71.03

Although this formula represents in a single number the magnitude of internal TL in AU, to monitor and control the training process it is important to have a valid measure even during competitions, to be able to compare these values with the same found through the training periodisation. Consequently, these data can represent a valid example of internal TL which is sustained by the athletes during this kind of race.

Conclusion

During the last 10 years the performances in the 20-km RW are improved, both for the men and women. This enhancement requires a deep analysis of the factors that might influence the performances acting on the training because the main focus for the training methodology and the scientific research is to supply both to the athletes and coaches useful tools for the periodisation plans. On our opinion these improvement are the result of a several aspects matched together, such as: (i) to drive the RW training towards high intensities and, thus, to the quality area (without lose the volume), (ii) the utilization of the combined strength-endurance training, to improve the muscular components, and (iii) the necessity to have the right knowledge regarding how monitoring the internal TL both to plan the training and to face to high specialization reached by the 20-km race walkers.

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**POLISH REPRESENTATIVE'S START EFFECTIVENESS IN
ATHENS AND BENJING OLYMPIC GAMES IN 50 KM
RACE WALK AND TRAINING LOADS IN PRE-
COMPETITION PERIOD IN OLYMPIC YEARS**

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In coach's practice a very important issue is appropriate athlete's preparation for Olympic Games - the most important competition in four-year training cycle. Among many determinants of the sports result appropriate training loads are considered to be the most valid. Although there is a lot of general knowledge of solving that problem in race walkers or long distance runners, but in the light of experience one could put a provable hypothesis, that the problem of training for the most important competition and evaluation of potential possibility of result on specific preparation period, not only in athletics, is still open. It probably comes from the fact that training ability is often personal (Szopa and co. 2000). The consequence of this is the fact, that the process of gene expression of trait of the same heredity can have different course in athletes under influence of the same power and quality of training stimulus. It is caused by unique genotype, so it's no wonder, that in that case individual approach is extremely important.

Only a few become distinguished coaches, like artists become some creators of art (Costill 1976). Appreciating their talent it is worth to mention, that nowadays knowledge and studying new evidence based methods and training procedures of XXI century is the matter of success.

To induce desired adaptation changes, first of all in pre-competition period (PCPP) of race walkers and middle and long distance runners, non-invasive methods of physical efficiency level diagnosis with use of more precise, practical "field tests" and methods of evaluation of potential result in given time becomes very important. Among them the most popular are methods of evaluation of individual aerobic threshold (Chwalbińska-Moneta 1990). In Poland lactate threshold test become more and more used in practice and especially in athletic endurance events Jerzy Andrzej Zoladz test is being popularized (Żołądz and co. 1993, Żołądz 2001). Until now some studies

shown it's usefulness (most often after some methodology modification) in race walkers' training monitoring (Mleczeko, Sudoł, 2005 a, 2005 b), and in 50 km race walking result anticipation (Mirek and co. 2007).

Mentioned test was used by Olympian Grzegorz Sudol in preparation for his consecutive Olympic competition in Beijing. Both he and his coaches assumed that every older athlete reaches the stage of extensive load increase and the only chance to get desired adaptation changes is to increase training intensity. In that connection for planning intensity ranges and training loads structure in all four-year cycle one used parameters received in above mentioned test like threshold speed and threshold heart rate.

One took also possibility of use of those results for setting tactics for race walk in Olympic Games in Beijing and for prognosis of the result in that competition. It is worth to mention, that before Olympic Games in Athens one used less precise methods of setting training loads intensity ranges, using relations between rates of reaching maximal oxygen uptake, maximal heart rate and anaerobic threshold. Until now no one tried to evaluate mentioned techniques and methods auxiliary for training process and the quantity of used training loads in pre-competition preparation period (PCPPP) for Olympic Games of race walkers.

The aim of the study: 1. Presentation of quantity structure and training loads intensity of polish 50 km race walker in Olympic years 2004 and 2008.

2. Comparison of training loads in year cycle and in PCPP and that based setting the tactics and anticipation of the result in 50 km race walk in Olympic Games.

Hypothesis: 1. Considering reaching border lines capability by highest level athletes, one can assume, that in preparation to Olympic Games in Beijing, extensive training loads increase did not occurred and it could be intensified, what should bring positive changes in physiological and kinematics changes in applied exercise test.

2. One can assume that climate zone (Beijing) could have significant influence on competition result in 50 km race walk and it can be much worse than in previous Olympic Games in Athens.

Materials and methods

The material was training documentation of Grzegorz Sudol (GS) Olympian from 2004 and 2008. In both parallel seasons training loads records and

exercise tests results were analyzed. In present study one allowed only a part of documentation, considering test results and training loads realized in Olympic years and analyzed exactly eight weeks of PCPP before Olympic Games in Beijing and Athens.

In the first case it was period from 5. 07 – 27. 08 2004, and in the second from 30.06 to 22.08 2008 r.

For training purpose one assumed, that threshold speed and heart rate will be the basis of setting the three training loads zones:

1. Sub-threshold zone (HR_1 – up to 95% threshold $HR \times \text{min}^{-1}$),
2. Threshold zone (HR_2 - 96% - 100% threshold $HR \times \text{min}^{-1}$),
3. Super-threshold zone (HR_3 above 100% threshold $HR \times \text{min}^{-1}$).

Comparing heart rate in mentioned test (HR_1 , HR_2 , HR_3 zone), being resultant of increase of lactic acid caused by pyruvic nonoxidation in working muscle cells with arbitrarily based circulatory system liminal reactions in intensity ranges of continuous walk (Walking Endurance - WE) before Olympic Games in Athens it shows, great similarity between heart rate assumed as threshold zone limit in lactate test (HR_2) and arbitrarily determined range in anaerobic threshold test (WE_2). One assumed that determined basal taxonomy of training loads in both macrocycles allowed for quality and quantity comparison. In that connection in present study, according to made assumption, the compartment of sub-threshold zone will be WE_1 , threshold zone - WE_2 , and super-threshold zone - WE_3 .

In each of eight microcycles of PCPP one calculated:

- a. basic statistical parameters (\bar{x} i SD) of global training volume in eight microcycles of PCPP before Olympic Games in Athens and Beijing and allowing for division:
 - intensity range WE_1 , WE_2 , WE_3 , (prior to Athens Olympic Games),
 - sub-threshold zones HR_1 , threshold HR_2 , super-threshold HR_3 (prior to Beijing Olympic Games)
 - mean speeds in weekly microcycles of PCPP applied in three ranges and zones of training loads.
- b. Normalized difference indexes between the arithmetic means of training load structure in PCPP microcycles realized prior to Olympic Games in Athens and Beijing, from formula:

$$W_n = \frac{\bar{x}_b - \bar{x}_0}{S_0}, \text{ where } \bar{x}_b - \text{ arithmetic means of elements of}$$

training loads structure and speeds realized in microcycles PCPP prior to Olympic Games in Beijing

\bar{x}_0 - arithmetic means of elements of training loads structure and speeds realized in microcycles PCPP prior to Olympic Games in Athens, S_0 – standard deviation of elements of training loads structure and speeds realized in microcycles PCPP prior to Olympic Games in Athens.

- c. Points in T – Score scale from arithmetic means of elements of training loads structure (below, over and threshold zone) and speeds realized in microcycles PCPP prior to Olympic Games in Beijing, with Olympic Games in Athens results as reference from formula:

$$PKT = \frac{\bar{x}_b - \bar{x}_0}{S_0} \times 10 + 50 \text{ where } \bar{x}_b - \text{ arithmetic means of}$$

elements of training loads structure and speeds realized in microcycles PCPP prior to Olympic Games in Beijing,

\bar{x}_0 - arithmetic means of elements of training loads structure and speeds realized in microcycles PCPP prior to Olympic Games in Athens, S_0 – standard deviation of elements of training loads structure and speeds realized in microcycles PCPP prior to Olympic Games in Athens.

Results

1. Structure of volume and intensity of training loads of polish athlete in pre-competition preparation period for two Olympic Games in 50 km race walking

Preparation for Athens Olympic Games

In four-year preparation period for Olympic Games in Athens, including pre-Olympic competition preparation, GS' basic training mean was continuous walk realized in three intensity ranges: WE₁, WE₂, WE₃.

They were estimated on the strength of HR and speed reached in previously described test 1. In that connection one assumed following references for estimation of mentioned above walking intensities:

- WE₁ – HR and walking speed (sub-threshold >152 heart beats(hb) · min⁻¹)
- WE₂ – threshold HR (152 – 164 hb · min⁻¹, about 83 – 89% HR_{max}), *speed* – arithmetic mean calculated from speeds reached in mentioned above walking intensity ranges 5 x 5 km and 5 min. pause.

– WE₃ – HR and walking speed (super-threshold < 164 hb · min⁻¹).

As far as in training practice there were no difficulties with estimation of heart rate limits, which are characteristic for anaerobic threshold (in OG the athlete cover 50km with mean threshold HR 164 hb · min⁻¹), so there was a problem with walking speed during as important competition as Olympic Games.

In speed estimation, athlete based on control trainings – 5 km walk, 1 km pause with WE₁ speeds. On particular training 5 km speed (min – max) was 4:16 – 4: 19min/km. Converting the above parameters on mean walking speed in 50 km race walk athlete could get a result between: 3:33:20 – 3:35: 50. In Athens OG the athlete got a result of 3:49:09 with mean speed of 4:35/km and mean HR – 164 · min⁻¹.

Analyzing data concerning mean speeds in respective PCPP microcycles one can ascertain, that the athlete did not follow test results and did not bring those results to training practice. Concerning mean walking speed index – average walking speed in all 3 ranges in 1 to 6 PCPP microcycles, it shows, that they were much lower than it could come from undertaken training. This index kept on similar level and oscillated in 5 seconds limits (min-max: 4:49/km- 4:54/km). Only in last two microcycles large leaps of speed occurred reaching 15 seconds (7th week. – 5:01/km– 8th week 4:46/km).

Probably not satisfactory effects of test 1 caused that prior to Olympic Games in Athens one started took heed to popularized J.A. Zoladz test (test 2). It's worth mentioning, that in pre-Olympic preparation in 2004 this test was used by Grzegorz Sudol and the rest of Polish athletes who had qualification 8 weeks before Olympic competition. Results in tab.1.

Table 1. Test 1 results 8 weeks before Athens competition 30.06.2004

Measure	before	I exercise	II exercise	III exercise	IV exercise	V exercise
HR [hb/min]		143	153	162	173	183
t _{km} [min/km]		4:56	4:37	4:13	3:57	3:44
LA [mmol/l]	1,82	1,73	1,67	2,31	5,07	10,9
Distance [m]		1215	1310	1420	1515	1605

As a result of presented data (tab. 1) speed similar to this on the Olympics occurred one step below lactate threshold (1,67-2,31 LA), in lower HR than in competition ($153 \text{ hb} \cdot \text{min}^{-1}$).

Table 2 Training loads in Olympic year 2004 in one year mesocycle

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	2004	
1. km	5	10	4	14	22	10	25	25	17	19	6	4	12
2. km	15	16	17	50	50	57	35	25	16	20	45	25	31
3. km	80	74	79	36	28	33	40	50	67	61	49	71	57
total(h)	32	36	33	35	28	26	44	36	15	4	31	44	336

1. km - % training volume in sub-threshold zone, 2. km - % training volume in threshold zone, 3. km - % training volume in super-threshold zone

As it comes from analysis of presented data (tab. 2) total work amount was 336 hours, from which mean percentage of training in respective zones amount in level: super-threshold 12%, threshold 31% and sub-threshold 57% of total training volume in Olympic year. The greatest number of working hours was made in July and December and the smallest in October.

Training structure in preparation period for Olympic Games in Beijing

According to assumption of test 2, in preparation period for Beijing Olympic Games one set the training loads zones assumed arbitrarily relations between them and threshold HR of an athlete (HR_2 – circa $162 \text{ hb} \cdot \text{min}^{-1}$)

1. sub-threshold zone – HR_1 = below lower limit of threshold heart rate ($>150 \text{ hb} \cdot \text{min}^{-1}$),

2. threshold zone 90 – 100% threshold heart rate – $\text{HR}_2 = 150 - 162 \text{ hb} \cdot \text{min}^{-1}$,

3. super-threshold zone – HR_3 above upper limits ($<162 \text{ hb} \cdot \text{min}^{-1}$).

Also in that case, difficulties in transformation of the results concerning speed in exercise test to training practice and prognosis of a competition result. Concerning GS' Beijing Olympics result (3.47:17), speeds in test in PCPP mesocycle were much higher and they couldn't be mechanically transformed to training. In below collation there's remarkable debatable fact of setting the lactate threshold and its derivative.

Table 3. Lactate test results from 2008.06. 20 (pre-competition mesocycle).

HR	131	141	151	161	170
Distance (m)	1135	1270	1345	1400	1510
La	1,5	1,4	1,8	2,0	7,2
V	5:20	4:43	4:27	4:18	3:59
Increase in (m)		135	75	55	110

*LA before test 1,7 mmol^xl

As it comes from presented data in tab. 3 lactate threshold occurred at HR 161 and walking speed of 4:18 min/km. On that ground foreseeing the result on 50 km walk could be circa 3h 35min. The athlete's result was 3:47:17 with mean speed 4:32/km taking IX place.

Summary and discussion

Data analysis concerning dynamics of mean walking speed during trainings in both PCPPs for Olympics, shown quality differences. One should assume that more intensive training was made prior to Olympic Games in Beijing. It characterized with higher variability, in first 6 microcycles mean speed dispersion shown a lot of variation before Beijing Olympics – 15s, and in Athens – 5 s. In last microcycles one ascertained lowering of training loads prior to Beijing Olympics, and the increase of training intensity before Athens.

In both PCPPs one realized similar, very low training volume. Prior to Athens Olympic Games arithmetic mean of all intensity ranges WE amount 12,4 km per training (min: 10km – max: 15,6km), and prior to Beijing Olympics - 12,6 km (min 10,2 km – max 14, 3 km). Going back to the structure of training loads one can notice, that differences between more intensive loads (WE₂, WE₃ and HR₂, HR₃) were insignificant. Only aerobic training means were higher before Beijing Olympics. Similar relations between training loads prior to both Olympics one can notice in data analysis of normalization indexes and points in T – score scale for results in Beijing Olympic Games (tab.4)

Table 4. Normalized differentiation index of training volume and its structure in researched athlete and point values in T-score scale of study results prior to Beijing Olympics in comparison to Athens Olympic Games

weeks		I	II	III	IV	V	VI	VII	VIII
Km	T	58	47	50	51	48	53	55	49
	W	0,8	-0,3	0,00	0,1	-0,20	0,3	0,5	-0,1
V	T	50	50	48	47	45	53	53	60
	W	0,0	0,0	-0,2	-0,3	-0,5	0,3	0,3	1,0
1. Km	T	61	81	36	13	46	45	48	50
	W	1,1	3,1	-1,4	-3,7	-0,4	-0,5	-0,2	0,0
1. Km	T	65	44	62	50	50	52	54	41
	W	1,50	-0,6	1,2	0,0	0,0	0,2	0,4	-0,9
2. Km	T	49	55	51	48	47	49	64	48
	W	-0,1	0,5	0,1	-0,2	-0,3	-0,1	1,4	-0,2

T-point index in *T*-score scale, *W* – differentiation index, *Km* – global training volume, *1. km* - training volume in sub-threshold zone, *2. km* - training volume in threshold zone, *3. km* - training volume in super-threshold zone

Table 5 Training loads in Olympic year 2008 in one year mesocycle

months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	2008r
1. km	9	15	14	7	3	17	9	13	18	2	6	3	10
2. km	9	13	13	4	36	50	54	40	27	4	7	10	22
3. km	82	62	73	89	61	33	37	47	65	94	87	87	68
total(h)	41	35	46	33	14	39	39	41	30	8	16	42	384

1. km - % training volume in sub-threshold zone, 2. km - % training volume in threshold zone, 3. km - % training volume in super-threshold zone, total – total number of training hours

As it comes from analysis of presented data (tab. 5) in 2008 total work amount was 384 hours. Mean percentage of training in respective zones amount in level: super-threshold 10%, threshold 22% and sub-threshold 68% of total training volume. In analogical period in 2004 there were much more threshold and super-threshold level training means – totally 11% more

than in sub-threshold. In 2008 athlete's training hours were 50 higher what accounts for over 500 km difference in training diary.

There is a great probability, that the athlete despite high training experience can increase training loads, by kilometer number raise and training intensification. Own study results suggest, the need of further studies not only for explanation of the phenomenon in cognitive purpose, but first of all for very important training goals.

Conclusions

1. Athletes' individual concept of training loads can be found positive. In preparation for two Olympic Games the result in 50 km race walk his results were 3.49:02 in Athens and 3.47:17 in Beijing.
2. One can conclude, that climate zone, in which competition took place, after proper adaptation did not have high influence on the results.
3. Training experience in one Olympiad period allow to get near two minutes better result

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THE TRAINING LOAD ANALYSIS OF FEMALE COMPETITOR PRACTICING RACE WALKING - IN THE YEAR-LONG CYCLE

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Abstract

The year-long training cycle 2008/2009 analysis of the female competitor, Polish representative has been presented. The division of female competitor's year-long training cycle to main periods has been demonstrated:

1. Preparatory period 10.11.2008 - 17.04.2009

- the general preparation period 10.11.2008 - 04.01.2009
- the special preparation period 05.01.2009 - 22.02.2009
- direct start preparation 23.02. 2009 - 17.04. 2009

2. Starting period 17.04.2009. – 12.09.2009

3. Transitional period 13.09.2009 – 2.11.2009

The training measures used in year long training process have been discussed.

Moreover the competitor's external load values applied in the whole 2008/2009 season have been presented in Table 1.

Furthermore the values of competitor's loads used in particular training periods of 2008/2009 season have been shown in Table 2.

Figure 2 demonstrated the participation of training measure – efficiency, in year-long training plan divided into particular mesocycles.

Also the amount of starts, the competitor's distances, the result, the position in the particular start and event rank have been presented.

Finally the factors that influence achieving good sport result have been pointed in the conclusion.

Results

The sport training analysis is very complex and some obstacles might be met, i.e. how to assess precisely the rate and character of load in particular periods, cycles and training activities.

I present the year-long training cycle 2008/2009 analysis of the female competitor, Polish representative.

- age – 23 year old
- training experience – 8 years
- personal bests:
 - 5 km race walking - 21:46,
 - 10 km race walking - 46:06,
 - 20 km race walking - 1:34, 28.

The year-long training cycle of the female competitor practicing 20 km race walking can be divided into the following main periods:

1. Preparatory period 10.11.2008 - 17.04. 2009

- the general preparation period 10.11.2008 -04.01.2009,
- the special preparation period 05.01.2009 - 22.02.2009,
- direct start preparation 23.02. 2009 - 17.04. 2009,

2. Starting period 17.04.2009. – 12.09.2009.

3. Transitional period 13.09. 2009 – 2.11.2009.

The competitor started her preparations for 2009 season on 10.11.2008. The preparation period lasted until 17.04.2009. It consisted of 3 periods:

- the general preparation period lasted from 10.11.08 to 4.01.09 and has been designed for functional organism abilities development, strength, general and resistant endurance. It consisted of 8 mesocycles.
- the special preparation period started on 01.01.09 and finished on 22.02.09. The training capacity increase and intensity rise has been noticed during this period. The special preparation period consisted of 7 mesocycles.
- direct start preparation lasted from 23.02.09 to 17.04.09. This period has been destined to build the starting form of the competitor. Direct starting preparation consisted of 8 mesocycles. (4,6)

The competitor started her sport 2009 season (starting period) in Zaniemyśl on 18.04.09, it lasted until 22.09.09.

The main task in this mesocycle was to prepare for the main event of the season, through the starts. It was Senior Polish Championship for 20 km which took place on 1.08.09.

The transitional period fell on 23.09.09 until 2.11.09 and was characterised by competitor's active rest, psychical and energetic reconstruction.

Training measures used in the competitor's training: (4)

- OWCH-1 (General Walking Endurance – 1) – first level of intensity, to maintain previous training level, to perfect the functions of cardiovascular and respiration system. This level is in charge of removing fatigue products from the muscles. Physiologically it is the intensity below the oxygen balance.
- OWCH-2 (General Walking Endurance – 2) – second level of intensity, to work in full oxygen balance, it has important impact on training level. It is one of the basic training work form of the competitor for 20 km.
- WT (Tempo Endurance) - third level of intensity, it is similar to special endurance. In practice there is the possibility to work in the continual, repeated or variable form with the intensity exceeding the oxygen balance, so the effort is not fully compensated with oxygen.
- WS – (Special Endurance) directly influences the effort adaptation in race walking for 20km. It characterises with the speed reached whilst covering a training distance in relation to speed reached on the starting distance.
- R – rhythm – short repeated distances with the object of improving the competitor's speed.
- SPR - overall efficiency – exercises of all basic muscle groups.

The work capacity and its intensity consist of competitor's training load. We can plan and analyse the loads that the competitor undergoes as its external loads. That is why the methods are being searched all the time to precisely determine effectiveness of applied training loads. (6)

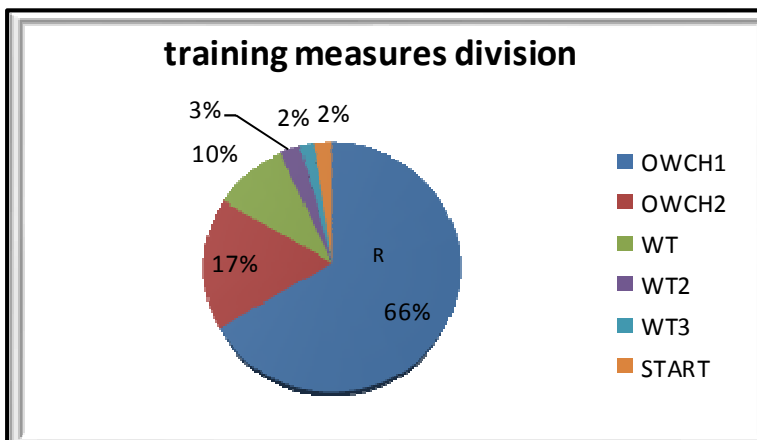
The competitor's external load values applied in the whole 2008/2009 season have been presented in Table 1.

Table 1. The training measures capacity in the year-long training cycle 2008/2009

	OWCH ₁	OWCH ₂	WT	WS	R	Start	Amount of starts	SPR /min/	Amount of trainings	Total km
capacity (km)	2801	720	409	114	73	98	10	3430	338	4215
% km	66,45	17,08	9,70	2,70	1,73	2,33				100 %

The competitor's training has been based on the oxygen work. She has covered much kilometer distance in the first intensity level, not exceeding oxygen ceiling. The main training measure used was OWCH1 (General Walking Endurance – 1) constituting 66, 45% of entire capacity. Second important training measure was walking in the second level of intensity, OWCH 2 - 17, 08 % of the covered distance during training and competitions. (1)

The percentage division of the used training measures in 2008/2009 season is presented in Figure 1.

**Figure 1.** The percentage division of training measures

The values of competitor's loads used in particular training periods of 2008/2009 season are presented in Table 2.

Table 2. The training measures capacity in particular periods of year-long training cycle 2008/2009

	OWCH ₁	OWCH ₂	WT	WS	R	Start	Amount of starts	Amount of trainings	SPR (min)	Total km
Preparatory period	1575	295	141	42	26	3	1	166	1620	2082
Starting period	1086	415	268	72	47	95	9	152	1450	1983
Transitional period	140	10						20	360	150
TOTAL	2801	720	409	114	73	98	10	338	3430	4215

The difference between two main mesocycles: preparatory and starting one in regard to covered kilometres (OWH1) is small, only 100 km, to the advantage of preparatory period. There is a decisive difference in other applied training measures. More of them have been used in starting mesocycle. (2, 3)

The competitor's physical fitness influences the sport level presented by her that is why it should be developed all the time whilst practising professional sport. (7)

The training measure participation – efficiency division into particular mesocycles in yearly training plan, presented as follows:

- In the preparatory period about 1620 min.
- In the starting period about 1450 min.
- In the transitional period about 360 min.

About 3430 min. have been devoted to SPR training in the entire 2008/09 season.

The main task of the efficiency activities (SPR) in the preparatory period was the development of all basic muscle groups. However in starting period the overall efficiency has been dedicated to both improving and

strengthening exercises, using this measure also as the competitor's organism regeneration against increasing training and starting loads.

Figure 2 shows the participation of training measure – efficiency, in yearly training plan divided into particular mesocycles.

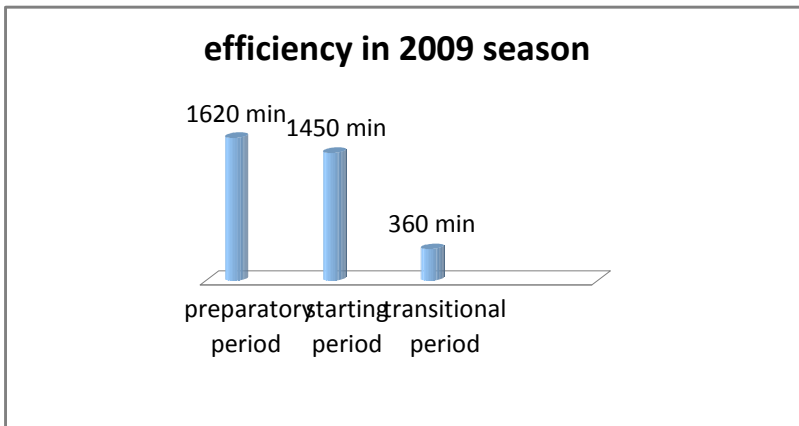


Figure 2. The training measure participation - efficiency, in yearly training plan

Table 3 presents the amount of starts, the competitor's distances, the result, the position in the particular start and event rank.

Table 3. The starts specification in 2009 season

No	date	distance	result	place	Event rank	location
1.	22.02	3.000m	14:05,67	1	Polish Indoor Championships	Spała
2.	18.04	20 km	1:37:40	3	National Permit	Zaniemyřl
3.	15.05	5.000 m	22:21.52	2	Academic Polish Championships	Katowice
4	24.05	20 km	1:39:22	16	European Cup	Metz
5.	13.06	5.000 m	22:44,82	1	Meeting	Rzeszów

6.	1.08	20 km	1:34:28	2	Polish Championships	Bydgoszcz
7.	14.08	5 km	21:46	1	Meeting	Mielec
8.	29.08	10 km	46:33	2	Meeting	Gdańsk
9.	5.09	5.000 m	22:50:06	2	League – Polish Club Championships	Kraków
10.	12.09	5 km	22:25	1	Meeting	Bratkowice

There were 10 starts in 2009 season, the competitor started 3 times in main distance for 20 km.

In the preparatory period of 2009 season the competitor started just once, during the Indoor Polish Championships for 3000m.

The starts and tests are means of training intensification that is why we have to doze them carefully and deliberately especially in the preparatory period.

The results achieved by the competitor in 2009 season confirm above regularity.

Conclusion

1. The training has been mainly based on the oxygen work. It results from many kilometres covered during the training.

2. Big amount of calm work capacity over endurance, especially in the preparatory period, has significant influence on implementing training tasks in the starting period.

3. Many supportive and regenerative exercises should be done in the starting period after the competitor's effort.

4. Both the implemented training measures and appropriate starting policy had great results in the form of personal bests for 5 km, 10 km and 20km in 2009 season.

5. There shouldn't be more than 3 - 4 starts for 20 km in one year, due to load on the competitor's body.

6. The main task is to prepare the competitor (race walker) starting for 20km, for uniform strength division during the whole distance.

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MECHANICAL ENERGY FLOW BETWEEN BODY SEGMENTS ON RACE WALKING

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Key words: Joint force, Joint force power, Joint torque, Joint torque power, Effectiveness of mechanical energy

Introduction

The manner of race walking which is defined by IAAF race walking rules is not a naturally obtained human skill as normal walking and running are acquired in childhood (Payne and Payne, 1981). In usual, people learn race walking technique after instructed by coaches. Therefore, the number of race walkers who have enough technique to participate and finish in international or national level competitions without disqualification depends on the number of coaches who can teach race walking technique properly. However, the race walking technique is usually instructed by a small number of coaches in many countries, based on their own experience as they were competitors. The increase of participants to race walking events and the world-wide promotion of race walking are the hot topic for the IAAF Race Walking committee. In order to increase the number of race walkers who can walk in a correct technique, it is important to establish a methodology for teaching race walking technique.

To walk in a higher speed in competition is one of the most important factors to achieve higher performance in race walking event in athletics. Although this factor should be analyzed first of all aspects of race walking, previous research on race walking technique started to analyze race walking, clarifying the differences between race walking and normal walking and differences between race walking and running (Payne, 1978; Murray et al., 1983; Fenton, 1984, White and Winter, 1985, Cairns et al, 1986).

Mechanisms of large walking speed in race walking have been analyzed form recent twenty-five years. Phillips and Jensen (1984) and Shimizu et al. (1994, 95) investigated stride, pitch and angle data in race walking which related to walking speed. Yamada et al. (1999, 2000) and Hoga et al. (2001) analyzed the time of loss of contact and the kinematics of lower extremities of race walkers to find the technical factor to confirm

IAAF race walking rules. Knicker and Loch (1990), Hoga et al. (2004,2007a), and Hoga (2005, 2006a) analyzed relationships between the kinematic variables of race walkers and the results of practical judgement by race walking judges in official races. Moreover, Hirakawa and Yoshida (2002, 2005, 2006) investigated the skill learning of race walking and proposed methods to evaluate personal technique of race walking and technical assistance for modification of their technique, based on the results of their research. As mentioned above, the number of research on race walking technique which related to high performance is increasing recently. There may be a background for that increase of demanding for researches to develop a methodology of exact race walking technique instruction.

To achieve high performances, it is important to maintain a walking speed over the race distance not only to obtain large walking speed because the race walking is an endurance event. Therefore, it is necessary to investigate the technical factors for the maintenance of walking speed. Briswalter et al. (1998) discussed about changes in walking motion by measuring a stride length, a vertical displacements of body segment and angles of body segment in the initial and final part in walking experiment which prolonged for three hours. However, authors did not analyze in detail the technical factors related to the maintenance of walking speed.

Economy of movement is one of the most important factors to achieve high performance in all endurance sports and biomechanical factors are concerns to the economy of movement (Frederick, 1992). Miura et al. (1971) suggested the importance of technique converting physiological energy to high performance in long-distance running events, typical endurance exercise. Williams and Cavanagh (1987) suggested that the mechanical energy which flows between body segments increase the effectiveness of physiological energy, while the volume of mechanical flows among body segments of whole body in distance running related to the amount of mechanical energy flow between both the legs (Enomoto et al., 1999). Large mechanical energy flow between recovery and support legs is reported in the study of normal walking (Winter and Robertson, 1978; Robertson and Winter, 1980) and sprint running (Chapman and Caldwell, 1983; Ae et al., 1988). Therefore, the volume of the mechanical energy flows among the whole body in race walking may likely to be assumed to be affected by the mechanical energy flow between both the legs. Furthermore, studies about the mechanical energy flow between both legs in race walking, the effective utilization of mechanical energy, and the technical factors that affect them may result in new findings which will

contribute to acquire high performance in race walking.

The purpose of this article is to review researches of race walking technique from the viewpoint of the mechanical energy flow among body segments, especially of the authors of present paper (Hoga et al., 2003, 2006b; Hoga, 2007b), referring previous research on that theme about other gait of bipedal human locomotion.

The effective utilization of mechanical energy, and the change of the mechanical energy within body segments

Cavanagh and Kram (1985) defined the index of effectiveness index of forces on human exercise as the ratio of the force used to the actual performance and the force applied to the outside of the body. However, Ae and Fujii (1996) commented to that index proposed by Cavanagh and Kram (1985) as not to indicate the effectiveness of the mechanical energy which is generated in the whole human body. Ae and Fujii (1996) defined the economy of exercise as containing the process which converts the physiological energy into the mechanical energy within human muscles (Figure 1). Ae and Fujii (1996) proposed that the economy of exercise should be divided into the efficiency and the effectiveness. In their proposal, the economy contains the process of convert the physiological energy into the mechanical energy in each human muscles and the effectiveness contains the process of convert the mechanical energy generated by each muscles into the performance of whole human body. The idea of efficiency and effectiveness, proposed above, may be useful to evaluate human technique in which they translate a physiological energy into a performance as running speed and walking speed. Thus, the effectiveness of mechanical energy utilization will be able to be analyzed in race walking because the effective use of the mechanical energy in running and normal walking were investigated.

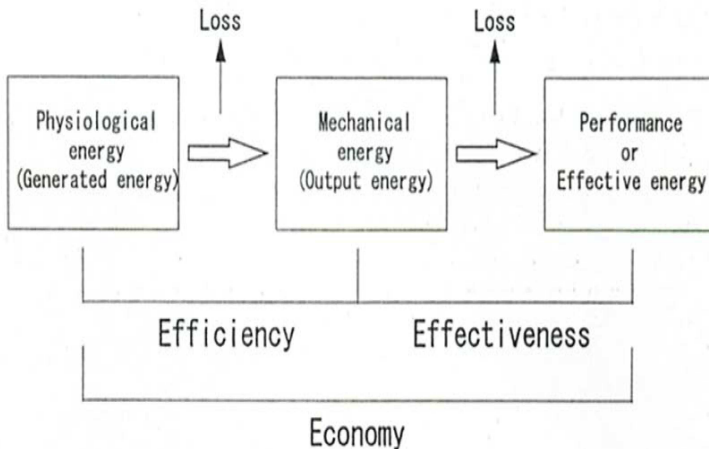


Figure 1 Flow of energy in human movement and three Es, i.e. efficiency, economy, and effectiveness (Ae and Fujii, 1996).

The effective utilization of mechanical energy within the whole body is based on two factors. One factor is the absorption and generation of the mechanical energy by human muscles about the joints of the body. The other factor is the mechanical energy flow between body segments which occurs at the joint connecting adjacent segments. Changes in the mechanical energy of each body segment are due to joint torque of the muscles about joints and due to the joint force acting between the adjacent parts. Outlines of mechanics of above are mentioned below and in Figure 2 (Winter, 1990).

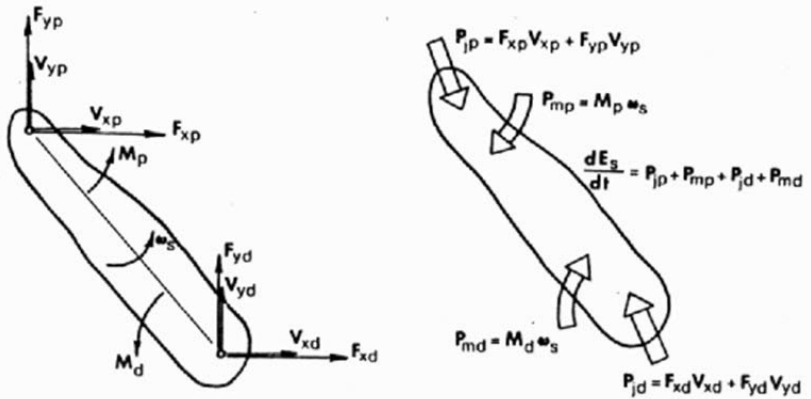


Figure 2 Left: Biomechanical variables describing the instantaneous state of a given segment in which passive energy transfers may occur at the proximal and distal joint centers and active transfers through the muscles at the proximal and distal ends. Joint forces acting at the proximal ends: F_{xp} , F_{yp} ; Velocity at the proximal ends: V_{xp} , V_{yp} ; Joint torques acting at the proximal ends: M_p ; Joint forces acting at the distal ends: F_{xd} , F_{yd} ; Velocity at the distal ends: V_{xd} , V_{yd} ; Joint torques acting at the distal ends: M_d ; Segment angular velocity: ω_s .

Right: Power balance as calculated using variables shown in the Left. The passive power flow at the proximal end P_{jp} , and distal end P_{jd} , combined with the active (muscle) power at the proximal end P_{mp} , and the distal end P_{md} must equal the rate of change of energy of the segment dE_s/dt (Winter, 1990).

Segment torque powers (P_{mp} , P_{md}), which are scalar products of joint torques (M_p , M_d) and segment angular velocity (ω_s), were generated by joint torques. These powers can be regarded as a powers absorbed or generated by muscles. Joint forces are applied at the joints connecting body segments. These forces push and pull each other body segments at that joint. Muscles about a joint do not act directly to ends of segments which adjacent each other at that joint, but muscle about other ends of that joints act to those segments indirectly via rigid body of segments. Therefore, a power which is generated by a joint force at a certain joints (P_{jp} , P_{jd} : inner product of joint force (F_{xp} , F_{yp} , F_{xd} , F_{yd}) and joint center velocity (V_{xp} , V_{yp} , V_{xd} , V_{yd})) can be sees as a transmitted power which is generated by the joints torque at other joint (Winter, 1990). Moreover, the segment torque power

and the joint force power affect the change of the mechanical energy of the body segments. The amount of the segment torque power and joint force power is equal to the change ratio of the mechanical energy in a certain segment (dE_s / dt) (Figure 2, Winter, 1990). Thus, these powers (P_{mp} , P_{md} , P_{jp} , P_{jd}) are called as the mechanical energy flow or the mechanical energy transfer (Pierrynowski et al., 1980). In addition, when the mechanical energy flows from the segment A to the segment B which is adjacent to the segment A, the mechanical energy of the segment A decrease and the mechanical energy of the segment B increase. These phenomena result in the deceleration or drop of the segment A and in the acceleration or elevation of the segment B.

The mechanical energy on normal walking and running

Winter and Robertson (1978) and Robertson and Winter (1980) performed investigations about the mechanical energy flow on normal walking. The authors measured ground reaction forces and analyzed walking motions by using two-dimensional motion analysis. They reported that not only the mechanical energy generation and absorption by the joint torque, but also the mechanical energy flow between body segments, especially the mechanical energy flow between the torso and the recovery leg, influenced the change of the mechanical energy of whole body.

Chapman and Caldwell (1983) and Ae et al. (1988) performed research the mechanical energy flow on sprint running. From the results of these analysts, the mechanical energy flow between the torso and the recovery leg due to the joint force at the recovery hip joint may influence the total mechanical energy change in the recovery leg. The mechanical energy may flow from the torso to the recover leg due to the hip joint force after toe-off in the recovery leg and flow from the recovery leg to the torso prior to the heel contact. Each flow is large than that in other part of recovery phases and affects the changes in mechanical energy of the entire recovery leg. Furthermore, the authors found that joint torque at the recovery hip influenced these hip joint forces. Affecting to the mechanical energy from the recovery leg to the torso and from the torso to the opposite leg, those torques helped forward and backward swing the recovery leg.

Williams and Cavanagh (1987) and Enomoto et al. (1999) investigated the change of the mechanical energy of the human body in distance running. Williams and Cavanagh (1987) performed an analysis of the mechanical energy change of each body segment by using the three-dimensional motion analysis and measured an oxygen uptake during sub-

maximal running on the treadmill on distance runners. As a result, subjects who were estimated as low economy of oxygen intake were significantly smaller than other subjects in the amount of mechanical energy flow in the torso and the lower extremities. The authors suggested that large mechanical energy flows between body segments reduced the consumption of physiological energy.

Enomoto et al. (1999) performed a two-dimensional motion analysis in official men's 5000m races on the track and field competition to clarify the technical factors for high performances in distance running. Subjects running in a high speed and with high performance used mechanical energy with high effectiveness. The amount of mechanical work of such kind of subject tended to be small and the mechanical energy transfer between both legs tended to be large. The authors suggested that a strong 'Scissors motion' by both two legs and fast forward swing of the recovery leg just after toe-off helps to obtain large amount of the mechanical energy flow between left and right legs. These previous researches above mentioned may suggest that factors for the changes of the mechanical energy of the whole body in race walking can be clarified as that of normal walking, spring running and distance running has been revealed by focusing on the mechanical energy flows between two legs.

Mechanical efficiency on race walking

The mechanical energy flows between body segments of whole body in normal walking and running has been studied. Cavagna and Franzetti (1981), Marchetti et al. (1982) analyzed about the change of the mechanical energy of the center of gravity of the whole body and the body segments.

Cavagna and Franzetti (1981) and Marchetti et al. (1982) performed measurements of ground reaction forces and the three-dimensional motion analysis on experiments of with male race walkers. National team race walkers of Italy participated to that experiment as subjects. From the measured data, authors calculated the mechanical energy change of the center of gravity during one race walking cycle of trials of different walking speeds in experiments.

Patterns of potential energy and kinetic energy during one cycle of race walking was almost same each other and these two decreased just after heel strike and increased just before toe-off. Those authors concluded that these patterns of potential and kinetic energies as the mechanical energy was accumulated just after heel strike and re-utilized during the late

half of support phase. They calculated the efficiency of the center of gravity with the change of mechanical energy of the center of gravity. As results, they concluded that the mechanical energy efficiency might be higher in race walking than in normal walking because of the accumulation and re-utilization of the mechanical energy but that the capacity of re-utilization for the mechanical energy in race walking is not higher than running. Thus, the efficiency of the mechanical energy in race walking is less than running.

Efficiency of race walking has been investigated from the viewpoint of comparing the mechanical energy of race walking to normal walking and running as above mentioned. However, technical factors to obtain large walking speed and maintain it throughout race distance has not been clarified yet. It may be important to discuss about the race walking technique from the view point of the effectiveness of the mechanical energy utilization (Ae and Fujii, 1996) in order to make clear the technical factors in which race walkers can translate physiological energy into performances effectively.

Mechanical energy flow between body segments in race walking

Hoga et al. (2003) and Hoga (2007b) performed researches on the mechanical energy flow in the recovery leg by using two-dimensional motion analyses on official races, in which world elite race walkers participated.

During the second half of the recovery phase, the mechanical energy flowed from the recovery foot to the torso via ankle, knee and hip joint by joint forces which acted backward at the proximal end of each segment of the recovery leg (Figure 3). These mechanical energy flows significantly related to the walking speed and the magnitude of the joint forces, which were generated by the hip extensors' torque, influenced to these mechanical energy flows.

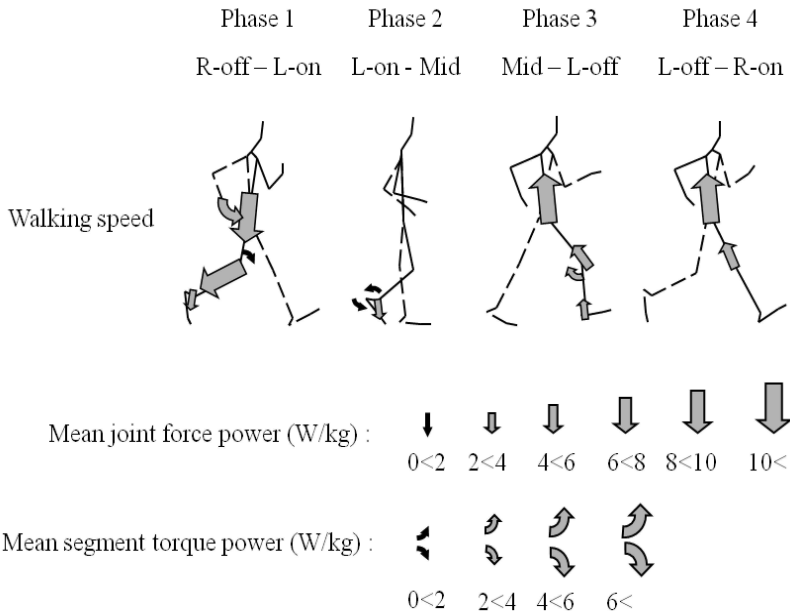


Figure 3 Mean joint force powers (straight arrows) and segment torque powers (curved arrows) of the recovery (right) leg that significantly relate to the walking speed during the right foot recovery phase ($N = 35$, $p < 0.05$) (Hoga, 2007).

In addition, such mechanical energy flows related to the maintenance of the walking speed throughout the 20km race. Maintained hip extensors' torque torques at the recovery hip joint in the second half of the 20km race resulted in the same magnitude of the backward hip joint force and the mechanical energy flow from the recovery leg to the torso.

Hoga et al. (2006b) and Hoga (2007b) analyzed the mechanical energy flows in the support leg of race walkers by using two-dimensional motion analysis and the measurement of the ground reaction forces on an experiment, in which Japanese elite race walkers participated as a part of subjects. As a result, they revealed that the mechanical energy flow which flowed from the torso to the support leg by the joint force at the support hip joint significantly related to the walking speed (Figure 4). The joint force

which acted forward at the proximal end of the support thigh influenced to the magnitude of that mechanical energy flow.

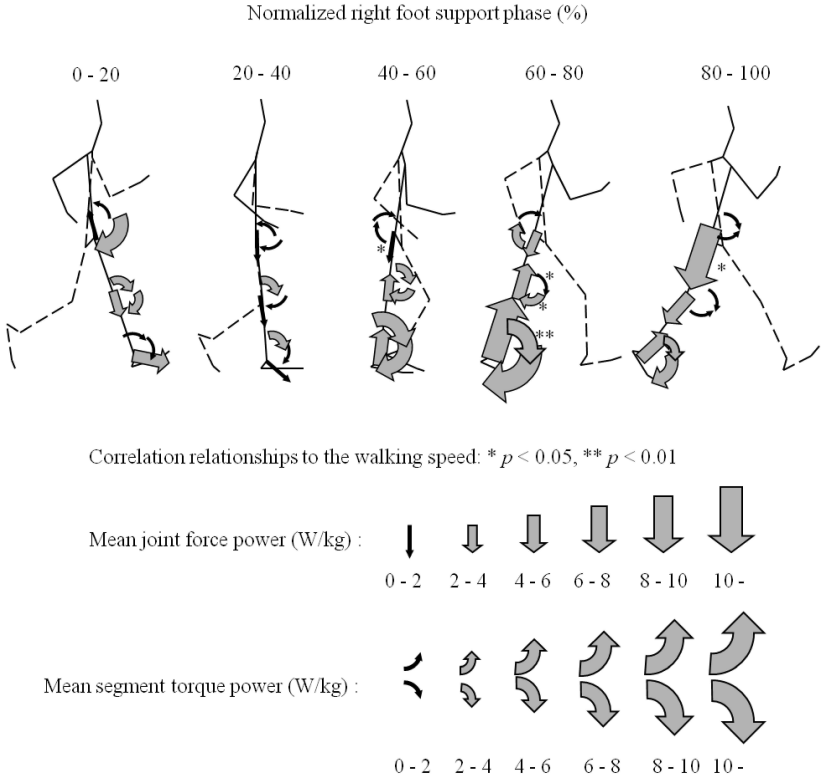


Figure 4 Mean joint force powers and segment torque powers for all subjects (N=12) during the normalized support phase (Hoga, 2007).

Referring to the results of studies which reported mechanical energy flows from the recovery leg to the torso and from the torso to the support leg, large mechanical energy flows from the recovery leg to the torso in the second half of the recovery phase might likely result in the increase of the mechanical energy of the torso and the support leg. In consequently, the increase of the mechanical energy of these segments might likely result in the large walking speed by the increase of the horizontal velocity of the torso and the support leg. Hoga et al. (2003,

2006b) reported that the walking speed significantly related both the step length and the step frequency. From that result, one question occurs how the increase of the horizontal velocity of the torso and the support leg contributed to obtain large walking speed.

Hoga (2007b) analyzed factors walking speed by using a multiple regression analysis for a walking speed during one step to a support time, flight time, support distance and flight distance in official races, in which male thirty-five walkers including world elite race walkers participated. Support distance had strongest relationships to the walking speed as a result. Short support time related to large walking speed. Race walking rule of 'loss of contact' constrains walkers to obtain large walking speed by large support distance. Thus, large mechanical energy flow from the recovery leg to the support leg via torso during the second half of the support phase might contribute to large walking speed by shortening the support time.

Hoga et al. (2006b) and Hoga (2007b) has not revealed factors of support hip joint forces for the large mechanical energy flow from the torso to the support leg by their two-dimensional motion analyses. To analyze factors for the support hip joint force, it is necessary to focus on the joint torques on the torso, the recovery leg and the upper extremities. The magnitude of joint torques in each joint of the recovery leg and about torso influences the joint force at the support hip via pelvis. However, pelvis moves in the three dimensional planes and it should be analyzed by three dimensional analyses to find that motion in detail.

Mechanical energy flow between body segments and joint torque about torso in race walking

The mechanical energy flow between the right and left legs may influence the motion of the pelvis and torso because both the right and left thigh connect to the pelvis at the hip joints. The joint force which acts at the recovery hip joint (proximal end) of the thigh pulls the recovery leg backward in the late recovery phase. The other hip joint force which acts at the support hip joint (proximal end) of the thigh pulls the support leg forward in the same phase. These two forces may change the direction by the action-reaction law. The joint force at the proximal end of the recovery thigh affects the forward pulling force at the recovery-side hip joint (distal end) of the pelvis. The joint force at the proximal end of the support thigh may affect the backward force at the support-side hip joint (distal end) of

the pelvis. These two forces may rotate the pelvis about vertical axis. Three-dimensional motions of race walking in the torso and pelvis have been taken as characteristic motions in race walking by practitioners.

In order to increase the stride length, it has been instructed that pelvis should rotate about the vertical axis swinging recovery leg forward (McCarthy, 1974; Kitchen, 1981; Payne and Payne, 1981; Salvage et al, 2000). However, the relationship between the motion of the torso and pelvis, and relationship of the torso and pelvis to the performance in race walking have not been clarified biomechanically. Therefore, Hoga (2007b) analyzed the relationship between the joint torque about the longitudinal axis of the torso and joint forces at the recovery and support hip joint by the three-dimensional motion analysis and the measurement of the ground reaction forces in the experiment of race walking.

As a result, the torque about the longitudinal axis of the torso may likely to act reducing the rotation of the pelvis in the late recovery phase (Figure 5). In addition, the joint force moment about the center of the pelvis by the hip joint force acting on both recovery and support hip balanced to the torque about the torso in the late support phase (Figure 6). Therefore, increase of the torque of trunk rotation swinging the recovery side hip backward in the second half of support phase may result in the larger joint force of the support hip in the direction of forward and the larger mechanical energy flow from the recovery leg to the support leg. Because this torque balanced to moments about the centre of the pelvis by joint forces both at the recovery and the support hip joints, large torque about the torso which reduce the forward swing of the recovery hip may important to obtain large mechanical energy flow from the recovery leg to the support leg and the large walking speed.

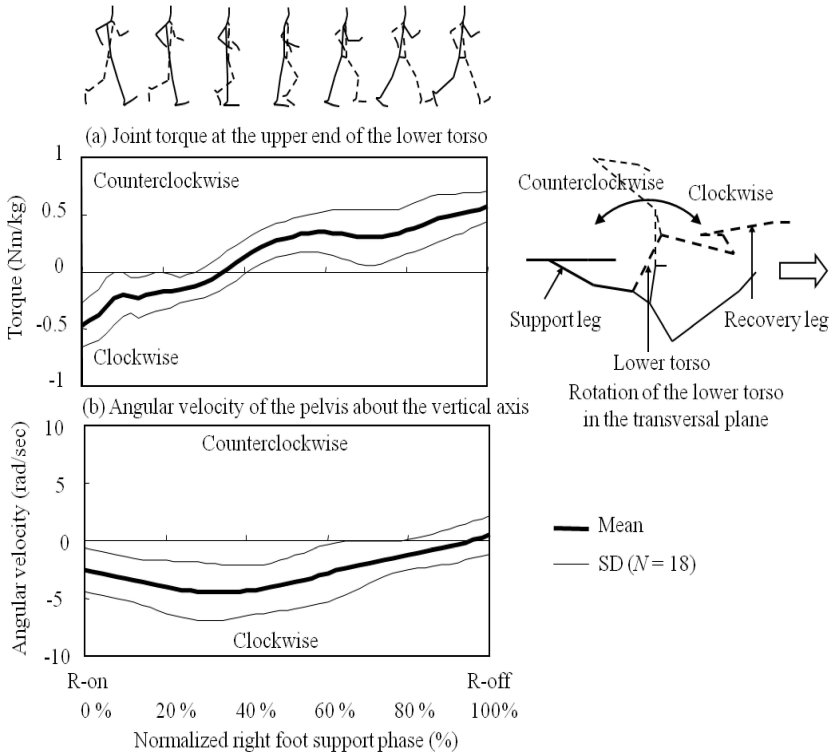


Figure 5 (a) Joint torque at the upper end of the lower and (b) Segment angular velocity of the lower torso about the Z axis in the absolute coordinates system of the average of all subjects on the experiment (Hoga, 2007).

If the torque about torso were small and did not balance to the moment of hip joint force, the pelvic rotation angular velocity which swings recovery leg forward would accelerate until the heel contact by the moment by the hip joint force. Such pelvic acceleration will result in larger impact to the leg at heel contact and large deceleration after heel contact because the recovery leg will accelerate to the heel contact. In addition, small torque about torso will cause to reduce the step frequency because small torque will reduce the initial swing speed of recovery leg. Thus, the torque

about torso shown in Figure 6 may contribute not only to large mechanical energy flow from the recovery leg to the support leg but also to reduce the deceleration after heel contact and to enhance the step frequency by the fast swing of the recovery phase.

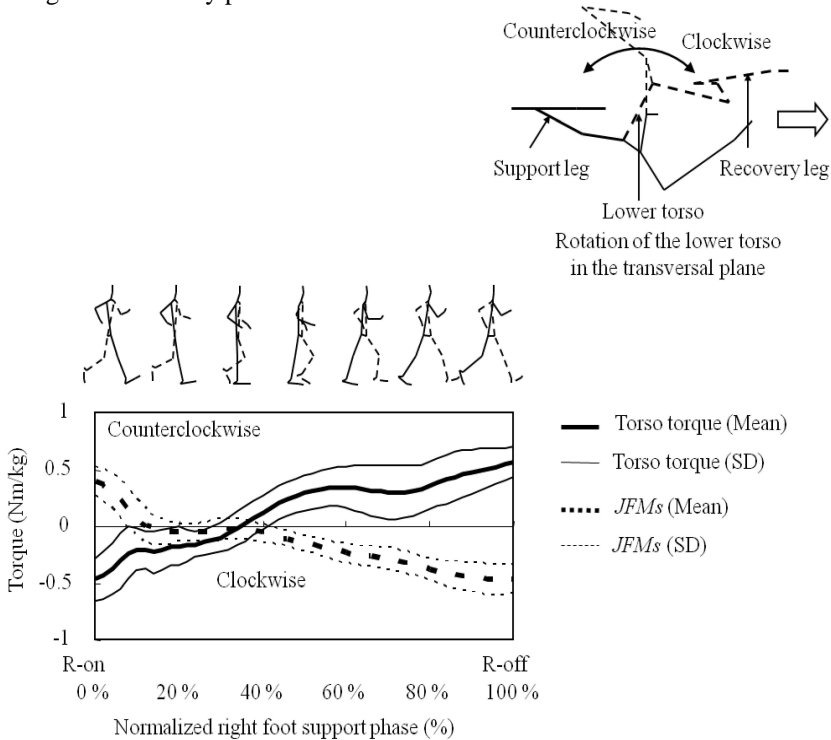


Figure 6 Joint torque at the upper end of the lower torso and the sum of the joint force moment of the right (support) and the left (recovery) hip about the center of the lower torso (*JFM*s) during the normalized right foot support phase (Hoga, 2007).

Practical implications for technical training of race walking

This text reviews previous researches about the effective utilization of the mechanical energy on human bipedal locomotion and discussed about the race walking technique from the view point of the mechanical energy flows among body segments reviewing our studies. Our

studies (Hoga et al., 2003, 2006b; Hoga, 2007b) revealed that the hip joint torque both two legs and the torque about the torso made large mechanical energy flow between two legs and resulted in the high effectiveness of utilization of the mechanical energy which are generated by whole body muscles.

However, we only discussed about the torque about the longitudinal axis of torso, and did not clarified mechanisms of the torso in the frontal plane which was notified as a particular movement of race walking (Cairns et al., 1986). We (Hoga, 2006a) has pointed out the importance of the motion of the support leg and support hip torque in the frontal plane. However, we have not clarified the detail relationship among these factors, the whole body motion and performance. Thus, these factors should be discussed in the future. And more, to connect these findings to the practical coaching, we should have an practical research on practical coaching.

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LOOKING AT THE BEST, A DETAILED ANALYSIS OF ELITE RACE WALKING TECHNIQUE

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Key words: race walking, technique analysis, high speed photography

Problem: How can we analyze race walkers under race conditions?

Aim: *Looking at the Best, A Detailed Analysis of Elite Race Walking Technique* is a synopsis of the book by the same name. By combining high resolution - high speed photography with computer software and detailed measurements, we paint an image of exactly how the best race walkers in the world stride forward at speeds approaching 10 mph (16 kph). Instead of theorizing body motions comprising ideal race walking technique, we analyze the race walkers from elite race walk competitions featuring the very best race walkers in the world.

Under race conditions (primarily at the 12th World Championships in Berlin), we see the good, bad and ugly with regard to technique. By using real race photographs we take the discussion out of the proverbial laboratory and examine how race walkers do what we want to do, race fast. While it is ideal to analyze real world conditions, it does present problems for gathering data. Our walkers were not aware of our project and therefore did not make themselves unobstructed for the camera. This often led to an errant arm or foot getting in the way. However, this does not detract from the usefulness of the photographs, and where necessary we have filled in areas of overlap. In addition, getting photographs of the best often means competing with the TV coverage of the event.

The definition of race walking requires that race walkers show no “visible to the human eye” loss of contact with the ground. After reviewing over 100,000 photos of elite race walkers, no walkers at top speed maintains contact. One controversy that is sure to develop as a result of our analysis is the obvious flight phase shown when high speed photography is utilized. Pushing themselves to world class speed requires that there is a “visible to the camera eye” flight phase. How long should this be is subjective, but by comparing sequences of photographs to judge’s tally sheets we begin to get a picture of what “visible to the human eye” really means.

Our discussion of technique goes much further than mere legality. We look at what is the ideal:

- duration of the flight phase as well as the distance travelled during loss of contact
- step length
- step length's ratio related to height
- the front vs. back distribution of the step
- angles between the feet and the ground at various points of the stride
- angles of the arms with relation to the body
- maximum height of the knee or foot during the stride
- pelvic and torso displacement
- points in the stride where various actions take place, such as the foot becoming parallel with the ground or the support leg flexing
- body lean

Our analysis includes 13 elite race walkers. It is important to note that there is not one style that is absolutely perfect for everyone. Variations in body structure, strength, and flexibility dictate that deviations occur. Unfortunately, due to technical difficulties and massive interference with the camera car, we do not obtain enough footage of the women to include a statistically relevant number of photographs to incorporate in this text.

All of the measurements for all of the walkers are correlated to each other so that we may see what patterns exist in the data gathered. Some found were ones that we expected, others were not.

Methodology: This section explains the methodology used to obtain the measurements shown in the charts and graphics within this text. We explain our protocol for obtaining each measurement and, where appropriate, indicate any perceived subjectiveness in obtaining the measurement. In addition, we show an example of each measurement. Please note as we are rounding off values for ease of presentation, some values shown in this explanation may vary slightly from the final values presented later as those values were computed without rounding.

There are two categories of measurements that we perform when analyzing race walkers from high speed photography. They are angular and scalar measurements. Angular measurements are relatively simple and performed by establishing two lines that form an angle and then measuring the magnitude of that angle. In this case, we used Adobe Photoshop CS4's

built-in measure tool to obtain the angle measurement. In contrast, establishing scalar measurement is a bit more complicated. First, we have to establish a scale for each series of photographs (a separate series is required for each athlete) and then use that scale for the rest of the measurements. We did this by using the height of an athlete as a known quantity and extrapolated how many pixels were in a meter from that measurement.

Our “model” for demonstrating the measurements is Norwegian Erik Tysse, photographed at the 12th IAAF World Championships in Athletics during the 20km event.

Glossary of Terms Used

While a glossary of terms is usually placed at the rear of a text, we are placing it before our methodology so there is no confusion in what we mean by some commonly used race walking terms.

Accuracy of Measurement: A subjective rating as to the exactness of the measurement. Very strong measurements were absolute in their accuracy, strong measurements were when we had a high degree of confidence, and moderate measurements had extenuating factors limiting their reliability.

Double Support Phase: When a race walker has both feet on the ground simultaneously.

Foot: While the formal definition of a foot is the terminal part of the leg where a person stands¹, we use it synonymously with the shoe of a race walker.

Heel: While the formal definition of a heel is the back of the foot below the ankle and behind the arch², we use it synonymously with the part of the shoe where the heel of the foot resides.

Step: The length of distance from the point of toe off from the foot of the supporting leg to the heel contact of the swing leg. Note, this measurement varies from the traditional step length as it is missing the length of a race walker's foot. If you wish to have this measurement it is easy enough to add into the value supplied.

Stride: The distance from initial contact of one foot to the following initial contact of the same foot.

Swing Phase: The portion of a race walker's stride where the foot has lost contact with the ground.

¹ Merriam-Webster.com, 2009

² Merriam-Webster.com, 2009

Support Phase: The portion of the race walker's stride where the foot is in contact with the ground.

Visible Loss of Contact to the Human Eye: The portion of a race walker's stride where both feet are simultaneously off the ground and the loss of contact is observable by the human eye.

List of Measurements

1) **Athlete's Height** – A direct value obtained from the IAAF website or from the athlete directly. If the height is not obtainable, a relative measure can be determined by using the known height of a walker within the same series of photographs. However, in most cases the height was obtained directly.

i.e.

Erik Tysse's Height = 1.90 Meters

2) **Pixels / Meter** - We determine the number of pixels used to represent a meter in each sequence of photographs by measuring the number of pixels used to represent the height of the race walker by the actual height of the race walker. To obtain the number of pixels representing the height of a race walker, we measure the number of pixels from the top of a race walker's head to the base of his foot (fully contacted plantar surface of the foot) when the race walker's supporting leg is under the body in the vertical position. (See Figure 1) By knowing the number of pixels for a walker's height, we can establish the number of pixels / meter in the photograph. We then can use this value to measure other scalar values. Figure 1

illustrates obtaining the number of pixels (1539) representing Erik Tysse's height. Therefore the # of pixels / meter for the Erik Tysse sequence is $1539 / 1.90 = 810.0$ pixels / meter.

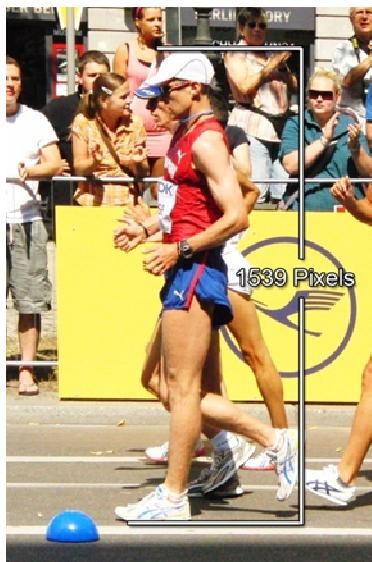


Figure 1

3) Step Length in Centimeters – One can define step length many different ways. The key is to measure it consistently from one race walker to another. We chose to represent the step length as the distance between the point where the toe of the rear foot leaves the ground and the point where the lead foot strikes the ground with the heel. Unfortunately, since no walker measured in this study exhibited a double support phase, the actual step distance required evaluating multiple frames simultaneously. In order to accurately measure the step length, we marked the position where the rear foot left the ground and drew a vertical line from that point upward. We took note along this vertical line for some immovable area of the background as our fixed point. We then opened the frame where the race walker's forward heel contacts the ground. Next, we located our fixed point and drew a vertical line downward. The step length is then the measurement of a horizontal line between the point of heel strike and our previously drawn vertical line. Care is taken that our lines are drawn at a 90 degree angle. This is easily achieved using features of Photoshop to prevent inaccuracies.

i.e.

Erik Tyse's step length = 852 pixels or 105 cm, see Figures 2 & 3



Figure 2



Figure 3

4) Step Length vs. Height - Since we want to compare quantitative measurements from one walker to another, it is best to normalize them against a walker's height to take into account different body sizes. Therefore, we compute the step length as a percentage of a walker's height. This is a straightforward calculation of Step Length / Height.

i.e.

Tysse's step length as a percentage of height = $852 / 1539 = 55.36\%$

5) Flight Distance – The distance covered by a race walker when both feet are not in contact with the ground. The flight distance is calculated by measuring the horizontal distance from the point of toe off to the front of the rear foot at the moment of heel contact with the forward foot. This is shown in Figure 4 with the point of toe off was determined in Calculation #3.

Measuring one's flight distance may be the most eye opening measurement of this study as the distance a walker travels without contact with the ground illustrates the controversy of whether a walker truly maintains contact with the ground. As we know an elite level a race walker does not have a double support phase where both feet are on the ground for at least a moment. However, how much of an elite walker's step is during the flight phase? The results might surprise you.

i.e. Erik Tysse's flight distance = 124 pixels or 15 cm

6) Flight Time – Ideally, if we used a higher frame rate in capturing our photographs, flight time could be directly measured more granularly using just the frames where a race walker has no contact with the ground. However, since a 40 fps camera was used, the most granular direct measurement is 25 milliseconds or $1/40^{\text{th}}$ of a second. This is the time between two frames. So if you have three frames, you can measure two $1/40^{\text{th}}$ of a second intervals for a total elapsed time of $1/20^{\text{th}}$ of a second.



Figure 4

That said, we can interpret how far off the walker is and extrapolate additional data in between frames. For example in a hypothetical case (not Tysse), if in the first frame the walker's rear foot is just beginning to toe off and the lead foot has yet to have contact with the ground, and in the 2nd frame there is significant loss of contact with both feet, and in the 3rd frame the lead foot has just made heel contact, then we might assume that the walker is off the ground for more than 50 milliseconds ($1/20^{\text{th}}$ of a second) shown by the interval between 3 frames.

However, if we measure the distance during the flight phase and divide it by the race walker's speed we can obtain a more accurate assessment of flight time. Since these photographs were taken under racing conditions, it is possible to estimate their speed fairly accurately. For example, Eric Tysse was walking at approximately 4:00/kilometer (or 4.1667 m/s). Since Tysse's flight distance = 15 cm, we can calculate his flight time as $0.15/4.1667 = .0360$ seconds or $1/28^{\text{th}}$ of a second. Note all of the 20km walkers in the study were walking at approximately 4:00 per kilometer. Similarly, the 50km walkers were walking at a pace within a few seconds of each other at 4:25 per kilometer.

7) Step Ratio – Race walkers often discuss the ratio made between a race walker's front and rear of the step. There are many ways to measure this value, and again, the key is to be consistent. We chose to measure the front portion of the step as the distance along a horizontal line drawn from the point of heel contact to a position directly beneath the middle of the hips. We can compute the portion of the step that is in front of the body by dividing the number of pixels in the front portion of the step by the total number of pixels in the step (Calculation #3). Note that the total step size includes a flight phase, which in this calculation is included in the rear portion of the step. Because of the flight phase we cannot



Figure 5

technically measure the percentage of the step behind the torso with a single frame. Since the point of toe off is technically the back end of the step, we use that position as the last point of the rear portion of the step. We then measure forward to the vertical position under the body. To simplify the process, we can *cheat*. Since we already know the step length from Calculation #3, we can simply subtract the forward portion of the step from the step length to obtain the rear portion of the step.

i.e.

Erik Tysse's front portion of the step in pixels = 263 (Direct Measure)

Erik Tysse's % front portion of the step = $263/852 = 30.86\%$

Erik Tysse's % rear portion of the step = $100\% - 30.86 = 69.14\%$

8) Average Vertical Loss of Contact – This is a direct measure from the frame where both feet have lost contact. This measure is a bit subjective depending upon the image. When there wasn't a shadow underfoot, it was sometimes difficult to pinpoint the exact point on the ground to begin measuring. In addition, the measurement is a small value and therefore, more sensitive to any inaccuracies inherent in our general measurement methodology.

i.e.

Erik Tysse's combined pixel height from the ground to each of his feet is a total of 46 pixels. Therefore, his average height from the ground is equal to 23 pixels. Next, we simply need to apply the conversion value for changing pixels to centimeters. Finally, since Americans understand inches better than meters we also convert the centimeters to inches so that the metrically challenged can better visualize the magnitude of the loss of contact.

Height in Centimeters = Avg. Vertical Loss of Contact (Measured in Pixels/Pixels per Meter * 100)

Height in Inches = Avg. Vertical Loss of Contact in Centimeters / 2.54.

i.e.

Erik Tysse's average vertical loss of contact in centimeters = $23 / 852 * 100 = 2.70 \text{ cm}$

Erik Tysse's average vertical loss of contact in inches = $2.70 / 2.54 = 1.06''$



Figure 6

9) Maximum Foot Height of the Swing Leg – The maximum height of the foot is measured from the highest point the foot is carried during the swing phase. This is usually slightly after toe off just as the leg begins to swing forward. The height is measured in pixels and then converted to meters.

i.e.

Erik Tysse's maximum foot height = $294 / 840 = 0.35\text{m}$ or 35cm



Figure 7

We can also calculate a race walker's maximum foot height as a percentage of their height to normalize the data for differences in body sizes.

i.e.

Erik Tysse's maximum foot height as a percentage of his height = $.35\text{m} / 1.9\text{m} = 18.4\%$

10) Maximum Knee Height of the Swing Leg – The maximum height of the knee is measured from the knee (top of the patella) at its highest point in the step as a vertical line drawn down to the ground. This is usually near the point at which the swing foot is parallel to the ground. The height is measured in pixels and then converted to meters. Note that the height is measured from the ground, not the foot.

i.e.

Erik Tysse's maximum knee height = $555 / 810 = .68\text{ m}$ or 68 cm

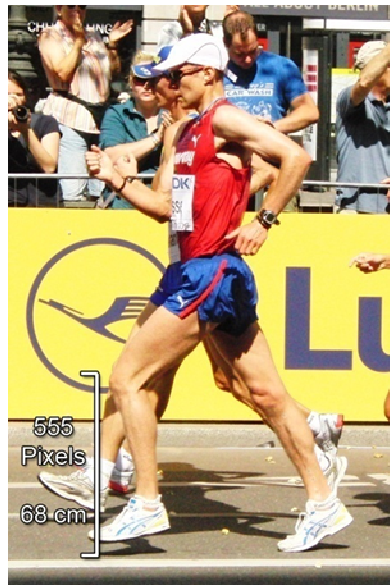


Figure 8

We can also calculate a race walker's maximum knee height as a percentage of their height to normalize the data for differences in body sizes.

i.e.

Erik Tysse's maximum knee height percentage = $.68 \text{ m} / 1.9 \text{ m} = 35.79\%$

11) Point of Knee Flexion During Propulsion (% of Rear Portion of the Step) – The percentage of distance of the rear portion of the step that occurs while the rear leg remains straightened is measured from a vertical line through the body to the front toe of the rear foot in the first frame where the race walker is bending the knee of the rear leg. The percentage of the step behind the body is then computed by dividing the # of pixels behind the body by the number of pixels of the step that occur in the rear of the body.



Figure 9



Figure 10

i.e.

Erik Tysse's % of rear portion of the step with a straightened knee =

$$375 / 852 * 69.14\% = 30.43\%$$

12) Point at Which the Swing Foot is Parallel to Ground (% of Forward Portion of Step) – The percentage is measured from the heel of the swing foot (when the foot is parallel to the ground) to the center point of the step. First, we determine the number of pixels in a line drawn perpendicular to a vertical line drawn directly under the body to the heel. Then the percentage is computed by dividing the # of pixels in front of the body by the number of pixels in the portion of the step that occurs in front of the body.

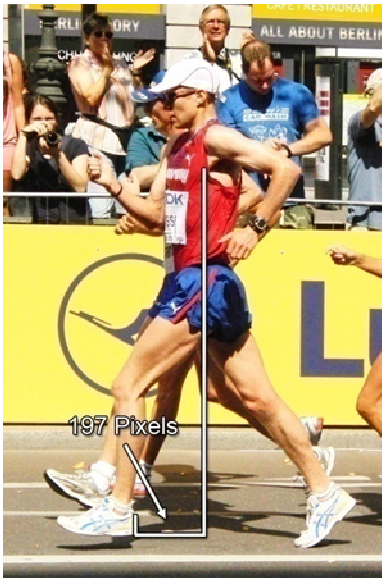


Figure 11



Figure 12

i.e.

Erik Tysse's % of forward portion of the step as the swing foot is parallel to the ground = $197 / 263 = 74.94\%$.

13) Rear Arm Angle – We measure the angle of the rear arm and a horizontal line from the shoulder. We perform the measurement on the race walker as he is about to toe off from the rear foot. We chose this position of the step because that is where the rear arm is usually in its highest position. The angle is measured between a horizontal line and a line drawn along the upper outer edge of the rear arm from the back of the shoulder to the edge of the elbow. This is shown in Figure 13.

i.e.

Erik Tysse's rear arm angle = 29.2 degrees

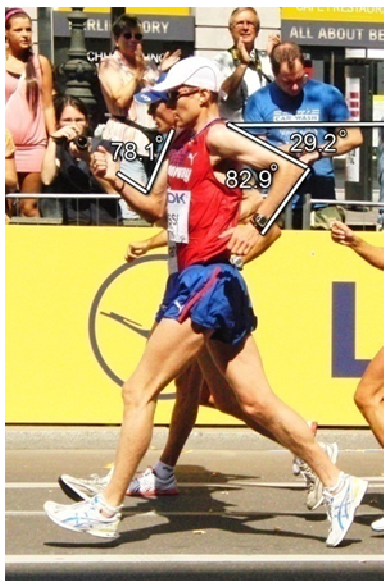


Figure 13

14) Rear Upper and Lower Arm Angle - The angle of the arm as it extends backward is measured along the outside of the arm from a line drawn from the top of the shoulder to the tip of the elbow and another line drawn from the tip of the elbow to the wrist joint (not including the hand) and drawn along the outside of the arm. For consistency, we measure the arm angle at the point of toe off in a race walker's step. This is shown in Figure 13.

i.e.

Erik Tysse's rear upper and lower Arm Angle = 82.9 degrees

15) Front Upper and Lower Arm Angle – The angle of the arm as it swings forward is measured along the inside of the arm from a line drawn from the front of the shoulder to the inside of the elbow (along the inside of the arm) and another line drawn from the elbow to wrist joint (not including the hand) along the inside of the arm. For consistency, we measure the angle at the point of toe off in a race walker's step. While this calculation is

fairly accurate, it can be off due to the variance angle as the arm swings across the body. Race walkers who swing their arm across their body more than others will affect the measured angle in front of the body. Therefore, there is little value to this measurement. However, it is included for completeness.

i.e.

Erik Tysse's front upper and lower arm angle = 78.1 degrees (Shown in Figure 13)

16) Forward Portion of the Arm Swing in Front of Body

– The amount of the arm swing in front of the body is measured from the farthest forward part of the arm/hand from the torso along a horizontal line drawn from the torso. For consistency we measure the value at the point of toe off in a race walker's step and when the inside leg is forward of the outside leg. The actual measurement is obtained in pixels and then converted to meters.

i.e.

Erik Tysse's forward position of the arm swing in front of the body = 31 cm

17) Rear Portion of the Arm Swing Behind the Body

– The amount of the arm swing behind the body is measured from the tip of the elbow along a horizontal line drawn to the rear of the torso. For consistency we measure the angle at the point of toe off in a race walker's step and when the inside leg is forward of the outside leg. The actual measurement is obtained in pixels and then converted to meters.

i.e.

i.e.

Erik Tysse's rear position of the arm swing behind the body = 25 cm

18) Ratio of Arm Swing in Front vs. Rear – Dividing calculation #17 / #18 gives us the proportion of arm swing in front of the body vs. behind the body.

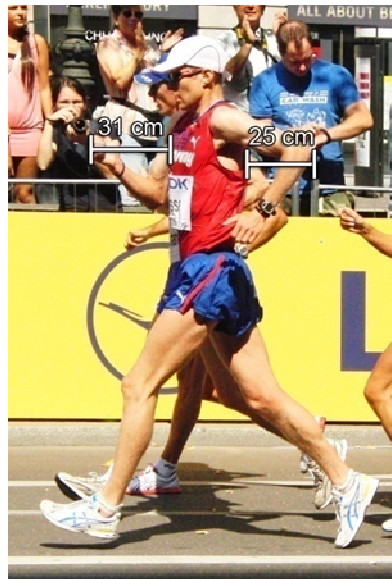


Figure 14

i.e.

Erik Tysse's ratio of arm swing in front vs. rear = 31 cm / 25 cm = 124%

19) Foot Angle at Contact – We measure the foot angle at contact when a race walker's swing foot makes initial contact with the ground. It is the angle formed between a horizontal line drawn along the ground with a line drawn tracing the bottom of the foot.

i.e.

Eric Tysse's foot angle at contact = 19.3 degrees



Figure 15

20) Leg Angle – We measure the leg angle when a race walker's swing foot makes initial contact with the ground. It is the angle formed between a vertical line drawn down from the center of the body and a line drawn tangent to the back of the forward leg.

i.e.

Eric Tysse's leg angle = 22.8 degrees

21) Ankle Plantar Flexion at Toe Off - We measure the angle of the rear foot and ankle from the frame where the race walker's rear foot has just lost contact. It is measured as the angle formed between two tangents. The first tangent is drawn from the ankle to the knee of the rear leg. The second tangent is drawn from the ankle of the rear leg to the toe of the rear foot.

i.e.

Eric Tysse's plantar flexion angle at toe off = 139.5 degrees.

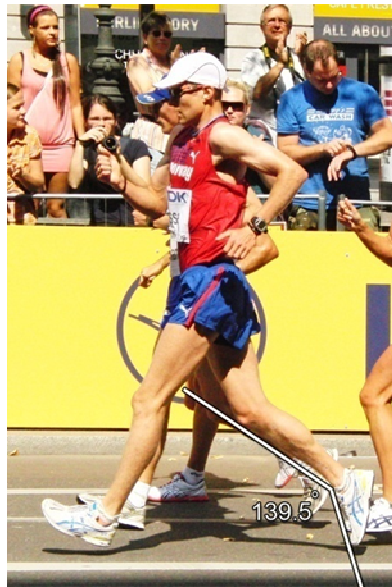


Figure 16

22) Body Lean – A direct measure obtained by determining the angle formed from a vertical line drawn through the middle of the body and another line perpendicular to the ground when the supporting leg is directly under the body and in the vertical position. Again, it is subjective at what point in the step you select for this measurement.

i.e.

Erik Tysse's body lean = 0 degrees

23) Torso Displacement- To measure torso displacement we compute the width of the torso at its maximum value as viewed from the side. We measure from just under the arm pit of the forward arm horizontally across the torso. This distance is measured in pixels and then converted to meters.
i.e.

Erik Tyse's torso displacement =
 $118 / 810 = .146 \text{ m}$ or 15 cm

24) Pelvic Displacement – To measure relative forward pelvic displacement, we compute the difference between the distances measured along a horizontal line when the pelvis is in a neutral position (Figure 19) and when it is fully extended forward (Figure 20). This distance is measured in pixels and then converted to centimeters.
i.e.

Erik Tyse's pelvic displacement =
 $26 \text{ cm} - 23 \text{ cm} = 3 \text{ cm}$

Given the inaccuracy of measuring the front and rear of the pelvis due to a walker's shirt hanging over the area to be measured, we have not included pelvic displacement as part of the correlations.

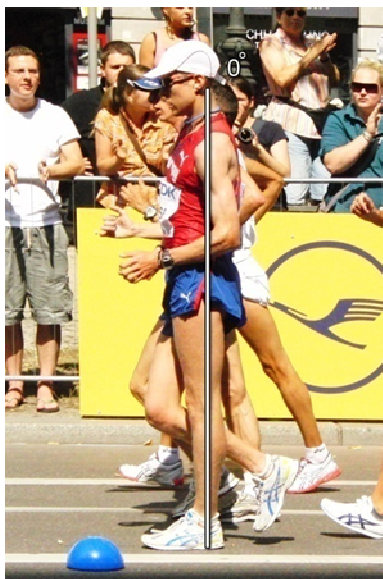


Figure 17



Figure 18



Figure 19



Figure 20

25) Leg Length – One can measure the leg length of a race walker subjectively. We measured the leg in the vertical position and estimated the top of the leg at the top of the pelvis. A vertical line was then drawn down to the base of the foot. Note, that all measurements include the sole of the shoe. This distance is measured in pixels and then converted to meters.

i.e.

Erik Tysse's leg length = 106 cm

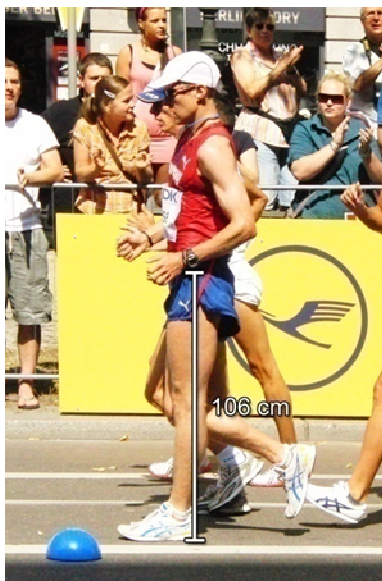


Figure 21

Outcomes:

When we started this study we really didn't know what we would find. We purposely didn't look at the correlations until it was nearly completed. As one would expect there were correlations that we expected to find and others we did not. It is important to note that a correlation does not imply a cause and effect. It simply indicates that in the sample data two values were related. Therefore, the ultimate significance of our findings is really up to the race walking community as a whole to determine.

When performing a correlation calculation using Excel we get a value from -1 to 1 that indicates the strength of a correlation. Values closer to -1 or 1 indicate a stronger correlation, while values closer to 0 indicate a weak correlation. For our study we took note of strong correlations as values between -1 and -.7 as well as .7 and 1. In addition, we noted weaker correlations between -.7 and -.5 as well as .5 and .7. These are arbitrary values and not absolute cutoffs. If a relationship has a correlation of .4999 one could argue it is still significant. If a correlation value is positive there is a direct relationship between the two values (See Figure 22). If a

correlation is negative, then there is an inverse relationship between the two values (See Figure 23).

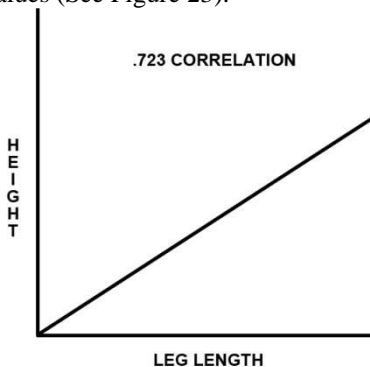


Figure 22

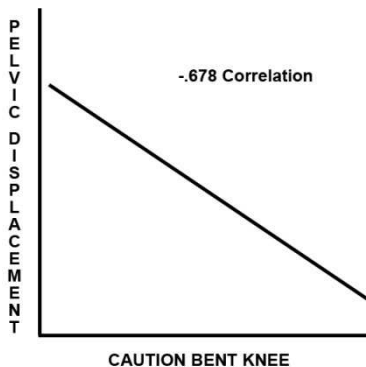


Figure 23

Please note that next to each measurement we indicate the “Accuracy of Measurement.” Given the nature of our data gathering, some measurements were more accurately obtained than others. Next to each measurement we indicate the “Accuracy of Measurement.” We indicate here any lack of precision in the measurement.

As to why there is a correlation, we’ve intentionally avoided answering that question here. Instead, we simply indicate the observations and leave conclusions for later. While some of the correlations have a logical biomechanical reason, others are fairly controversial. Indeed, during our peer review of this text, we didn’t all agree as to why some correlations existed. Therefore, in many cases we leave it to the race walking community to debate these findings and their relevance.

Measurement: Height	Accuracy of Measurement: Very Strong
In most cases the heights were gathered from the IAAF website and assumed to be correct.	
Correlated Field: Leg Length	Correlation Value: .67
There is a direct and obvious correlation between a walker’s height and their leg length as leg length is a major component in one’s height.	
Correlated Field: Knee Height	Correlation Value: .72
There is a direct and obvious correlation between a walker’s height and the height they carry their knee.	

Measurement: Step Length	Accuracy of Measurement: Strong
Having defined step length as the distance from toe off to heel contact, it is easy to measure this distance even if it requires obtaining it from multiple photographs.	
Correlated Field: Leg Length	Correlation Value: .52
There is a direct and obvious correlation between a walker's step length and their leg length, as leg length is a major component in one's step length.	
Correlated Field: Flight Distance	Correlation Value: .53
While it makes sense that longer steps correlate with a longer flight distance, some of this correlation is due to the way we are measuring step length. Since we are computing it from the point of toe off to the point of heel contact, clearly any flight distance is added to the step length measurement and thus forms the correlation. This should not be looked at as a bias as much as that flight distance is a component of step length. The question is what is an acceptable amount of flight distance (either as an absolute value or as a relative value) to step length at a given speed? This is a question we will not answer, but propose it for debate.	
Correlated Field: Red Cards for Bent Knee	Correlation Value: -.59
The shorter a walker's step length the more red cards for Bent Knee they received.	
Measurement: Flight Distance	Accuracy of Measurement: Strong
Correlated Field: Step Length	Correlation Value: .53
We observed that the greater a walker's flight distance, the greater the walker's step length.	
Correlated Field: Vertical Loss of Contact	Correlation Value: .64
We observed that the greater a walker's flight distance, the greater the walker's loss of contact along the vertical axis.	
Correlated Field: % Step in Front of Body	Correlation Value: -.83
We observed that the greater a walker's flight distance, the smaller the portion of the walker's stride was in front of the body.	
Correlated Field: Torso Displacement	Correlation Value: .55
We observed that the greater a walker's flight distance, the greater the torso displacement.	
Correlated Field: Caution Loss of Contact	Correlation Value: .65
We observed that the greater a walker's flight distance, the more cautions for loss of contact the walker received.	
Correlated Field: Red Cards for Loss of Contact	Correlation Value: .55
We observed that the greater a walker's flight distance, the more red cards for loss of contact the walker received.	

Note that the correlations between the percentage of step in front of the body and the percentage of step behind the body are the inverse of each other. Therefore the percentage of step behind the body is not shown. It's simply equal to the correlation for the percentage of step behind the body multiplied by -1.

Measurement: Percent of Step in Front of the Body	Accuracy of Measurement: Strong
Historically, walkers used to form an isosceles triangle with their legs, thus having a nearly 50/50 front to back ratio of their step. As the years have progressed, walkers now walk with a smaller portion of their step in front of their body than behind. The following correlations show that there may be many components of the step that are related to this shift in walking style.	
Correlated Field: Vertical Loss of Contact	Correlation Value: -.63
As the percentage of the step in front of a walker's body increases, the amount of loss of contact measured in the vertical direction is decreased.	
Correlated Field: Max Foot Height	Correlation Value: -.57
As the percentage of the step in front of a walker's body increases, the maximum height of the swing leg's knee is lowered.	
Correlated Field: Rear Upper to Lower Arm Angle	Correlation Value: .65
Walkers who have a larger angle between their upper and lower arm also exhibit a larger percentage of their step in front of the body. As it is difficult to extend the step behind the body without enlisting many other body actions, walkers with a larger arm angle tend to reach forward in front of the body and thus affect the step ratio.	
Correlated Field: Flight Distance	Correlation Value: -.83
We observed that as the percentage of the step in front of the body increases, the distance a walker travels horizontally while off the ground decreases.	
Correlated Field: Caution For Loss of Contact	Correlation Value: -.53
As walkers increased the percentage of their step in front of the body, the number of cautions they received for loss of contact decreased.	
Correlated Field: Hip Rotation Ratio	Correlation Value: -.58
As walkers increased the percentage of their step in front of the body, their hip rotation ratio decreased.	

Measurement: Vertical Loss of Contact	Accuracy of Measurement: Moderate
We would hope that the vertical loss of contact value would be small, as such, given our method of measuring there is a degree of margin for error in the value. In addition, the exact moment we caught the walker in flight might change our result. We used the largest vertical loss of contact measurement in the sequence of photographs for our measurement. We did this because judges give cautions and proposals for disqualification when seeing the walker at their worst.	
Correlated Field: Max Foot Height	Correlation Value: .64
Walkers that carry their swing foot higher certainly look like they are off the ground more than their low foot swinging counterparts. Our data shows that most walkers carrying their swing foot higher also have a greater loss of contact along the vertical axis.	
Correlated Field: Flight Distance	Correlation Value: .64
Since most of the walkers in the study were racing at a relatively similar pace, one can infer how the higher a walker launches themselves into the air, the longer the horizontal component of their loss of contact will be.	
Correlated Field: % Step in Front of the Body	Correlation Value: -.63
Walkers with a greater vertical loss of contact had a smaller portion of their step in front of their	

body.

Measurement: Max Foot Height	Accuracy of Measurement: Strong
Correlated Field: Vertical Loss of Contact	Correlation Value: .64
While one can't say that in all cases a higher foot is an indication of an increased vertical loss of contact with the ground, our data shows that walkers with a high foot carriage also exhibit a higher vertical loss of contact. We are not prescribing that since there is a correlation, that judges use the foot height as a determination of loss of contact. Judges should still look for the loss of contact when determining cautions or proposals for disqualification.	
Correlated Field: % Step in Front	Correlation Value: -.57
We observed that as the maximum foot height of the swing leg increases, the percentage of the step in front of the body decreases.	
Correlated Field: Caution for Bent Knee	Correlation Value: -.59
We observed that as the maximum foot height of the swing leg increases, the number of cautions for bent knee a walker receives decreases.	
Correlated Field: Hip Rotation Ratio	Correlation Value: .59
We observed that as the maximum foot height of the swing leg increases, walker's hip rotation ratio increases.	

Measurement: Max Knee Height	Accuracy of Measurement: Strong
Correlated Field: Height	Correlation Value: .72
Clearly a person who is taller carries the knee of their swing leg higher through the step. This should not be surprising.	
Correlated Field: Torso Displacement	Correlation Value: -.50
We observed that as the maximum knee height of the swing leg increases that a walker's torso displacement decreases.	
Correlated Field: Rear Arm Distance	Correlation Value: .78
When race walkers pull their arms too far behind their body, the excessive motion propagates to other aspects of the step. Our data shows that race walkers who pull their arm farther back also drive their knee higher.	

Measurement: Point of Knee Flexion	Accuracy of Measurement: Strong
Correlated Field: Front Upper/Lower Arm Angle	Correlation Value: -.57
We observed that as a person's point of knee flexion was further away from the body the arm angle between the upper and lower arm decreased.	

Measurement: Position the Foot is Parallel	Accuracy of Measurement: Strong
There were no significant correlations with any measurement for position the foot is parallel to the ground.	

Measurement: Rear Upper Arm Angle	Accuracy of Measurement: Strong
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There were no significant correlations with any measurement for rear upper arm angle.	
Measurement: Rear Upper and Lower Arm Angle	Accuracy of Measurement: Strong
Correlated Field: Front % Step	Correlation Value: .65
We observed that as the angle between a walker's upper and lower arm increases, the percentage of their step in front of the body increases.	
Correlated Field: Foot Angle at Contact	Correlation Value: .57
We observed that as the angle between a walker's upper and lower arm increases, the foot angle at contact increases.	
Correlated Field: Body Lean	Correlation Value: .56
We observed that as the angle between a walker's upper and lower arm increases, the walker's body lean increases.	
Correlated Field: Hip Rotation Ratio	Correlation Value: -.52
We observed that as the angle between a walker's upper and lower arm increases, the walker's hip rotation ratio decreases.	
Measurement: Front Arm Distance	Accuracy of Measurement: Strong
Correlated Field: Caution for Bent Knee	Correlation Value: -.63
We observed that the farther in front of the body a walker's arm swings, the less cautions for bent knee are received.	
Correlated Field: Red Cards for Bent Knee	Correlation Value: -.65
We observed that the farther in front of the body a walker's arm swings, the less red cards for bent knee are received.	
Measurement: Rear Arm Distance	Accuracy of Measurement: Strong
Correlated Field: Knee Height	Correlation Value: .78
We observed that the farther a walker's arm swings in behind of the body, the higher the maximum knee height of the swing leg.	
Correlated Field: Torso Displacement	Correlation Value: -.57
We observed that the farther a walker's arm swings in behind of the body, the less torso displacement occurs.	
Measurement: Foot Angle at Contact	Accuracy of Measurement: Strong
Correlated Field: Leg Length	Correlation Value: -.62
We observed that the foot angle at contact increases for walkers who have shorter legs.	
Correlated Field: Caution for Bent Knee	Correlation Value: .58
While coaches promote pointing the toe higher on heel contact to prevent novice race walkers from bending the knee at heel contact, it appears from our data that athletes who have an excessively high foot angle at contact (~30 degrees or more) have significantly higher cautions for bent knee as well as red cards.	
Measurement: Front Leg Angle	Accuracy of Measurement: Strong
There were no significant correlations with any measurement for a walker's front leg angle.	

Measurement: Plantar Flexion Angle	Accuracy of Measurement: Strong
There were no significant correlations with any measurement for a walker's plantar flexion angle.	
Measurement: Body Lean	Accuracy of Measurement: Strong
Since very few walkers exhibited body lean, we must question the validity of the correlations with body lean.	
Correlated Field: Leg Length	Correlation Value: -.77
We observed that walkers who had a larger body lean had a shorter leg length.	
Correlated Field: Rear Upper/Lower Arm Angle	Correlation Value: .56
We observed that walkers who had a larger body lean had a greater angle between the upper and lower arm when the arm is behind the body.	
Correlated Field: Red Cards for Loss of Contact	Correlation Value: .57
We observed that walkers who had a larger body lean received more red cards for loss of contact.	
Measurement: Torso Displacement	Accuracy of Measurement: Strong
Correlated Field: Knee Height	Correlation Value: -.50
We observed that as the torso displacement increases, the maximum knee height of a walker's swing leg is lower.	
Correlated Field: Rear Arm Distance	Correlation Value: -.57
We observed that as the torso displacement increases, the distance a walker's rear arm swings back decreases.	
Measurement: Hip Rotation Ratio	Accuracy of Measurement: Moderate
In some walkers it was difficult to determine exactly where the hips were due to their shirt hanging out of their shorts.	
Correlated Field: Percent of Step in Front of the Body	Correlation Value: -.58
We observed that walkers with greater hip rotation ratio had a smaller percentage of their step in front of their body.	
Correlated Field: Foot Height	Correlation Value: .59
We observed that walkers with greater hip rotation ratio had a higher foot height.	
Correlated Field: Rear Upper/Lower Arm Angle	Correlation Value: -.52
We observed that walkers with greater hip rotation ratio had a smaller rear upper/lower arm angle.	
Correlated Field: Cautions for Bent Knee	Correlation Value: -.55
We observed that walkers with greater hip rotation ratio received less cautions for bent knee.	
Correlated Field: Red Cards for Bent Knee	Correlation Value: -.64
We observed that walkers with greater hip rotation ratio received less red cards for Bent Knee.	
Measurement: Leg Length	Accuracy of Measurement: Moderate
It was difficult to determine the exact position of the top of the leg as this is a subjective measurement.	

Correlated Field: Height	Correlation Value: .67
We observed that taller walkers had longer legs.	
Correlated Field: Step Length	Correlation Value: .52
We observed that walkers with longer legs took a longer step.	
Correlated Field: Foot Angle at Contact	Correlation Value: -.62
We observed that walkers with longer legs had a significantly smaller foot angle at contact.	
Correlated Field: Caution Bent Knee	Correlation Value: -.60
We observed that walkers with longer legs received fewer cautions for bent knee.	
Correlated Field: Total Red Cards	Correlation Value: -.61
We observed that walkers with longer legs received fewer red cards.	
Correlated Field: Body Lean	Correlation Value: -.77
We observed that walkers with longer legs had less body lean.	
Correlated Field: Red Cards for Loss of Contact	Correlation Value: -.51
We observed that walkers with longer legs received less red cards for loss of contact.	

Measurement: Cautions for Loss of Contact	Accuracy of Measurement: Strong
Correlated Field: Front % Step	Correlation Value: -.53
We observed that walkers with more cautions for loss of contact had a smaller portion of their step in front of the body.	
Correlated Field: Flight Distance	Correlation Value: .65
We observed that walkers with more cautions for loss of contact had a larger flight distance.	
Correlated Field: Total Red Cards	Correlation Value: .81
We observed that walkers with more cautions for loss of contact also received a greater number of red cards.	
Correlated Field: Red Cards for Loss of Contact	Correlation Value: .80
We observed that walkers with more cautions for loss of contact also received a greater number of red cards for loss of contact	

Measurement: Cautions for Bent Knee	Accuracy of Measurement: Strong
Correlated Field: Step Length	Correlation Value: .50
We observed that walkers with more cautions for bent knee had a longer step length.	
Correlated Field: Foot Angle at Contact	Correlation Value: .58
We observed that walkers with more cautions for bent knee had a larger foot angle at contact.	
Correlated Field: Foot Height	Correlation Value: -.59
We observed that walkers with more cautions for bent knee had a lower maximum foot height on the swing leg.	
Correlated Field: Hip Rotation Ratio	Correlation Value: -.55
We observed that walkers with more cautions for bent knee had a smaller hip rotation ratio.	

Correlated Field: Leg Length	Correlation Value: -.60
We observed that walkers with more cautions for bent knee had a shorter leg length.	
Correlated Field: Front Arm Distance	Correlation Value: -.63
We observed that walkers with more cautions for bent knee had a shorter arm swing in front of the body.	
Correlated Field: Total Red Cards	Correlation Value: .63
We observed that walkers with more cautions for bent knee received more red cards.	
Correlated Field: Red Cards for Bent Knee	Correlation Value: .82
We observed that walkers with more cautions for bent knee received more red cards for bent knee.	

Measurement: Total Red Cards	Accuracy of Measurement: Strong
Correlated Field: Leg Length	Correlation Value: -.61
We observed that walkers who received more red cards had a shorter leg length.	
Correlated Field: Caution for Loss of Contact	Correlation Value: .81
We observed that walkers who received more red cards had more cautions for loss of contact.	
Correlated Field: Caution for Bent Knee	Correlation Value: .63
We observed that walkers who received more red cards had more cautions for bent knee.	
Correlated Field: Red Cards for Loss of Contact	Correlation Value: .76
We observed that walkers who received more red cards had more red cards for Loss of Contact.	
Correlated Field: Red Cards for Bent Leg	Correlation Value: .64
We observed that walkers who received more red cards had more red cards for Bent Knee.	

Measurement: Red Card for Loss of Contact	Accuracy of Measurement: Direct Measure
Correlated Field: Flight Distance	Correlation Value: .55
We observed that walkers who received more red cards for loss of contact violations had a greater flight distance.	
Correlated Field: Leg Length	Correlation Value: -.51
We observed that walkers who received more red cards for loss of contact had shorter legs.	
Correlated Field: Cautions for Loss of Contact	Correlation Value: .80
We observed that walkers who received more red cards for loss of contact violations received more cautions for loss of contact.	
Correlated Field: Total Red Cards	Correlation Value: .76
We observed that walkers who received more red cards for loss of contact violations also received more total red cards.	
Correlated Field: Body Lean	Correlation Value: .57
We observed that walkers who received more red cards for bent knee violations had more body lean.	

Measurement: Red Card for Bent Knee	Accuracy of Measurement: Direct Measure
Correlated Field: Step Length	Correlation Value: -.59
We observed that walkers who received more red cards for bent knee violations had a shorter stride. This correlation (-.70) is even more pronounced when we look at Step Length as a % of height.	
Correlated Field: Front Arm Distance	Correlation Value: -.65
We observed that walkers who received more red cards for bent knee violations carried their arms closer to their body.	
Correlated Field: Hip Rotation Ratio	Correlation Value: -.64
We observed that walkers who received more red cards for bent knee violations had a smaller hip rotation ratio.	
Correlated Field: Cautions for Bent Knee	Correlation Value: .82
We observed that walkers who received more red cards for bent knee violations received more cautions for bent knee violations.	
Correlated Field: Total Red Cards	Correlation Value: .64
We observed that walkers who received more red cards for bent knee violations received more red cards overall.	

Derived Values

As we reviewed the correlations, there was no end to the comparisons we could make. This was especially true when it came to derived values. Values that could be derived from a combination of fields might yield correlations which were not obvious from directly measured values. The most notable of these was step rate. We did not directly measure a walker's step rate, but by combing step length (with the addition of the foot length) with pace, we can determine a walker's step rate. Since Dr. Tom Eastler has studied step rate of the world's best walkers at the World Cup and Olympics it was interesting to compare his directly measured values with our calculated values. They matched within a step or two per minute. As for correlations, we didn't find much that was statistically relevant. Step rate correlated to step length (-.61) and Rear Upper Arm Angle (-.51). Another interesting derived value was Step Length / Leg Length. The intent of looking at this ratio against all other measurements was to see if a walker potentially was overstriding related to any other measurement. A larger Step Length / Leg Length ratio might mean the walker is utilizing their hips effectively or it might mean they are overstriding. Our correlation showed that walkers with a higher ratio also had higher average loss of contact with the ground, greater flight distance, and more forward body lean.

Conclusion:

Four measurements had no other measurement that correlated with them in a statistically relevant manner. One could draw the conclusion that these measurements (point of knee flexion, front leg angle, plantar flexion angle, and rear upper arm angle) do not relate in any way to any of the other measurements, and thus their relevance to good race walking technique would be minimal. However, it may also mean that at an elite level the variation in each measurement wasn't enough to relate to other measurements significantly.

Acceptable Loss of Contact?

What does the parenthetical portion of the race walking definition "to the human eye" really mean? Does the definition mean a walker is not walking legally if they have any loss of contact with the ground? If one takes this hard line approach, then every walker in our study should have been disqualified for loss of contact, since no one had a double support phase for the entire race. If, contrarily, you believe that the rule states that as long as you can't see the loss of contact, that the walker is legal, does this mean that the change in wording of the definition of race walking has altered what is considered legal race walking technique? Therefore, we pose the question, did the definition change from "steps so taken that unbroken contact with the ground is maintained" to the parenthetical phrase of "to the human eye" change the way judges evaluated walkers?

We also ask, why did the definition change? Some theorize that it's because the media was pointing out loss of contact via slow motion video and that without the parenthetical phrase everyone would be considered in violation of the definition. Others may theorize it was needed since the style of race walking changed in the 1960's. Back then race walkers made an isosceles triangle with their legs, thus having a nearly 50/50 front to back ratio to their step. Since race walkers began to walk with less of their stride in front of their body, it appears that their flight phase grew. This is at least statistically demonstrated in our data as the three walkers with the largest flight distances also had the smallest portion of their stride in front of the body (Sanchez, Brugnetti, and Yamazaki). So one could also ask the question of how much of a walker's step should be behind the body if in doing so leads to the walker having a greater loss of contact?

How long can a walker be in loss of contact with the ground before it is noticeable to the human eye? Many judges, coaches and athletes state that if a walker has loss of contact for three frames of a video camera they should be disqualified. How much is that? In today's modern electronic world, one

first has to define what type of video camera is being used. If we assume a 30 fps camera and the simplistic estimation given here, then the lower bound for detection would be just above 0.06666 seconds or $1/15^{\text{th}}$ of a second. How does this compare to our results? The only walker disqualified in our sample study was Yamazaki who had two proposals for disqualification for loss of contact and one for bent knee. He had a flight time of .054 seconds, below the theoretical threshold. In contrast, Brugnetti was on the precipice of the threshold at .065 seconds and he received two proposals for disqualification due to loss of contact. Additionally, Sanchez was at .072 seconds of loss of contact, but only received one proposal for disqualification due to loss of contact.

Accuracy of Judging Calls

Interestingly one walker (Yamasaki) who received four cautions for bent knee also received four cautions for loss of contact and three proposals for disqualification (two loss of contact and one bent knee). When looking at the complete stride sequence of Yamazaki as well as other photographs of him throughout the race we saw no evidence of violating the bent knee portion of the definition of race walking. Could some of Yamasaki's cautions for bent knee have been erroneously attributed to the wrong violation? We can't answer that question. However, since a statistically high number of bent knee calls are given in elite competition and very few photographs exist where elite race walkers are in violation of the bent knee clause of the definition of race walking, we feel the question must be asked. On a side note, we are not stating that this necessarily holds true for masters or novice race walking where they might violate the bent knee portion of the definition more often.

After looking at the measurements, images, and correlations, we saw many concerns related to judging. Do you think our judging needs to be changed? We will not answer that question, but pose a parallel to the dilemma Major League Baseball faces in their top product, the World Series. Anyone watching the games saw how the many of the umpiring decisions were under the microscope of instant replay. As such, many close calls were deemed by viewers as not accurate. Major League Baseball has some tough decisions to make and so do we.

Questions or Answers?

As a result of our study you probably have more questions than answers. Any statistically relevant correlation can lead to discussion and debate as to its relevance. Clearly there are many implications to judging race walking. We hope our study encourages a much needed debate about race walking

technique and judging. We hope its data become the foundation for others to explore what great race walking technique really means based on concrete values instead of just theories.

Summary: After analyzing the photographs of 13 of the best race walkers in the world, many measurements correlate to each other. The significance of these correlations is left as a discussion for the reader. Clearly the biggest observation of this study is the dramatic difference in flight phases amongst the elite athletes and the number of proposals for disqualification they received. Another very interesting correlation was the increase in flight phase as the percentage of a race walkers stride decreases in front of the body. These and other correlations need to be studied more closely so that we improve the credibility of our sport.

ATHLETIC WALKING IN TERMS OF KINEMATIC PARAMETERS OF WALKING STEP

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Abstract

The author is in the contribution summarizing the knowledge about the dynamic changes of kinematic coefficients in walking step and the laterality of lower body by increasing the speed of tempo by athletic walking of the top walkers of Slovakia. Raising of walking speed is realised by extending the walk length, extending the time and by decreasing the walking frequency. From the lateral point of view, the lower body is tending to the failure of velocity parameters of the support leg and the total pace velocity by the walking speed $4'25 - 4'15 \text{ min.km}^1$ and $4'10 - 3'55 \text{ min.km}^1$. Exactly this speed is characteristic for the walking speed on the level of special walking tempo.

Key words: athletics walk, kinematics parameters, walking stride, dynamic changes, laterality,

Introduction

By the technique evaluation in the sport practice we also go upon the evaluation of biomechanic characteristics. These events concretize the movement technique of a sportsman in its kinematic and dynamic exposal. From the point of view on the technique of periodic movements, it is possible to evaluate also the laterality, let us say, the concern of sides on the explanation of the sport achievement. The kinematic coefficients of running walk are giving us these possibilities of length, time – air (flight) and velocity characteristics.

Athletic walking is an athletic discipline with special demands on the walking technique, which results from athletic rules (Korčok, Pupiš, 2006). These specific kinematics of walkers also results from from these rules. We have to work not only on the physical preparedness of the competitor, but also on the walking technique of kinetic exposal. Rational technique is characterized by the minimalization of deprivation by the speed within the touch on the vertical line. This phase affects the level of special preparedness of thigh flexors and glute muscles, tending to place of the vertical adminicle (Kampmiller et al. 1998). From the point of walking

preparation we have to mention the necessity of higher level of special abilities. The potential possibilities are made by their levels, which are inserted into the structure of achievement and into the specific co-ordinating structures of walking by the adequate methodology and aimed choices (Broďáni et al. 2003).

The importance of economical walking techniques is visible during the championship, when by walk length from 90 – 110 cm the walker makes from 200 – 220 steps/hour, that is 16 500 steps on 20 km championship (Korčok, Pupiš, 2006). The development of inner muscles and also the intramuscular koordination and the use of flexible mechanism of kinetic system structure, enables the walkers to increase their efficiency by the minimal demands on energetic systems (Vanderka, 2008). The praxis shows, that the effect of heredity by the walk economy has higher importance than years of training.

We can encounter with the length, time – air (flight) and velocity characteristics of the walking step in some works of Slovak authors: Broďáni – Šelinger, 2001; Broďáni, 2005ab; Broďáni – Vavák – Šelinger, 2003; Kampmiller et al. 1998, and so on.

Problem

The contribution is summarizing the results of works written by Slovak authors, who are dealing with kinematic aspects of athletic walking from the point of dynamic and laterality of lower body by increasing the walking speed.

Methodology

The monitored file was composed of 8 members of Slovak representative team in sport walking. They were chosen as a complex on the basis of reached results in their sport career, stabile achievements, regulated technique and their potentation ahead in their further sport career. By obtaining the empiric data, we used the methodics by Šelinger (1993), so called „locometer“. By this „locometer“ we have these parametres: time of support, time of flight, trajectory during the support, trajectory during the flight. From these indications we calculated: lenght of step, speed of step, speed during the support, speed during the flight, step frequency. Together was measured 200 walking doublesteps with kinematic parameters by different walking speeds from 6´10 min. km-1 to 3´39 min. km-1. The

measures were passed of in the athletic hall and on 20 m measured distance. The walkers could control their technique and thereby follow the rules of walking steps till the highest speed of walking.

By the analyzing of kinematic coefficients of dynamics (Broďáni – Šelinger, 2001) were the obtained data classified into the sequence according to progress of walking speed. The assessment of tendency by kinematic coefficients was realized by the linear regressive line. Together with regressive line we mention also the regressive equation and the index of reliability R2.

By the analysis of laterality of lower body (Broďáni – Šelinger – Vavák, 2004) we chose the dominant and non-dominant leg according to reached average speed of walk in measured distance by even and odd steps. We classified the obtained data into the order according to progress of walking speed. We also analyzed 8 speed zones, two of them are in the „zone of breaking the technique“, the lap it over by its speed. We analyze 8 speed zones (each zone $n = 25$ walking doublesteps): 6'10 - 5'00 min.km-1; 5'00 - 4'40 min.km-1; 4'40 - 4'25 min.km-1; 4'25 - 4'15 min.km-1; 4'15 - 4'10 min.km-1; 4'10 - 3'55 min.km-1; 3'55 - 3'47 min.km-1; 3'47 - 3'39 min.km-1. The significance of contrasts between the dominant and non-dominant leg was monitored by T – test. The statistic importance of contrasts is criticized on $p < 0,01^{**}$ and $p < 0,05^*$ importance level.

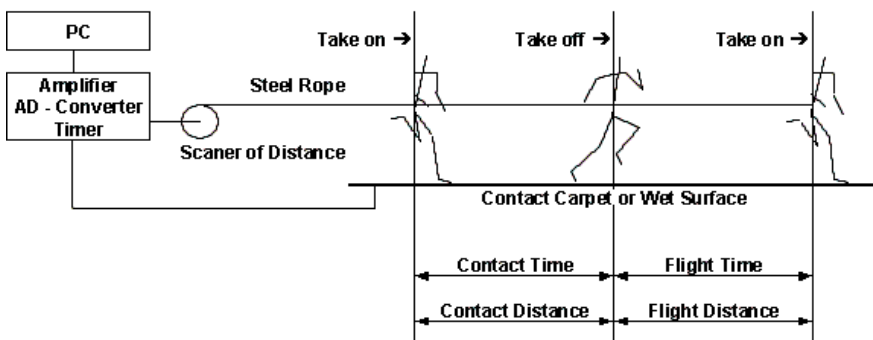


Figure 1 The principle of measurement kinematical parameters (Šelinger, 1993).

Results

The work Broďáni – Šelinger (2001) is demonstrating the dynamic changes of walking step by increasing the walking speed tempo, it generalizes and characterizes the patterns from the point of walking step technique by the Slovak representatives. From the point of kinematic coefficients is by increasing the walking speed also extending the length of a walk, the supporting time and the walk frequency is minimizing (chart 1, 2, 3). The tendency of walkers is to increase the walking speed by more effective support in the phase of pulping, but also with expanding its action angle, that prevents to break the rules about the contact with the ground. The ambition of walkers is to go as fast as they can from the fastest phase into the walk and in the vertical phase.

The authors Broďáni – Šelinger – Vavák (2004) present the kinematic parameters from the point of lower body laterality. They point out the predominant symmetry of lateral walking technique by the top walkers. Despite of predominant symmetry of walking step, the authors noticed some important contrasts between dominant and non-dominant leg in velocity zones : 4'25 – 4'15 min.km-1 and 4'10 – 3'55 min.km-1 (table 1 and table 2). The contrast pertain to walking speed, time of flight, trajectory during the flight, speed during the support and the length of walk. The constructed partial ambidexterity by the top walkers is connected to the prolonged training and phased decreasing laterality of both legs. It compensates the concern of lower body on the speed of walking step.

From the point of preparation of walkers we point out the necessity of higher level of special power abilities manifested in passive compensation of lower body laterality by critical speeds, we are able to ensure the requests of athletic walking rules and to achieve better achievements.

We suppose, that with increasing distance and tideness can be showed some contrasts between kinematic parameters of walking steps in the doublesteps. The constructed symmetry of dominant and non-dominant leg is probably nearly connected with the level of special endurance manifested on the whole race distance.

Enclosures

Specific kinematics results from athletic walking rules. The holdback of continuous contact with ground and pulping of knee insists claims on the economy of kinetic activity. The dynamics of walking step is

realized by extending of walking step, by extending the support time and by decreasing the walking frequency.

The laterality of walking steps is manifested in the equability of kinematic coefficients by increasing the athletic walking speed. We notice the anomalies in kinematic parameters only by achieving the walking speed at the level of special tempo, which is characteristic for given discipline.

The expressed and partly constructed ambidexterity of kinematic parameters by top walkers is closely connected with the prolonged training.

In consideration of mentioned walking step dynamics, it is possible the beating up walking technique by developing intramuscular and muscular coordination and exploitation of flexible movement of kinetic organism system. The sport preparation with focus on the development of special power abilities will facilitate the walkers to increase the kinetic economy and also its efficiency.

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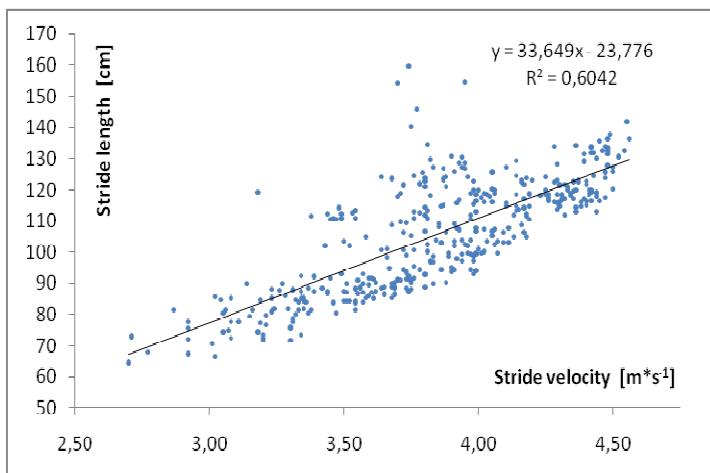


Chart 1 Relationship stride length and stride velocity in athletic walking

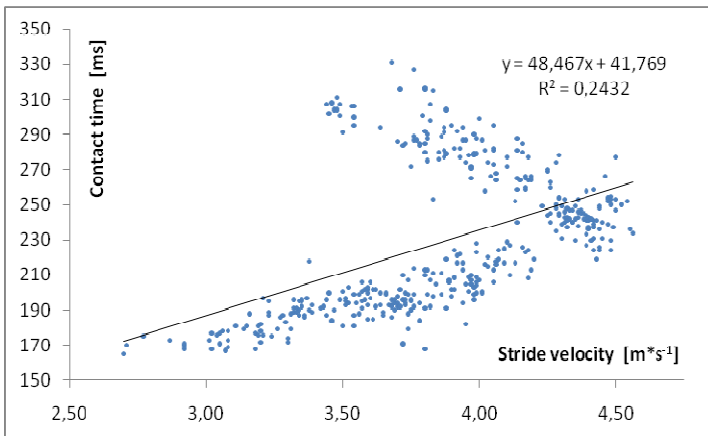


Chart 2 Relationship contact time and stride velocity in athletic walking

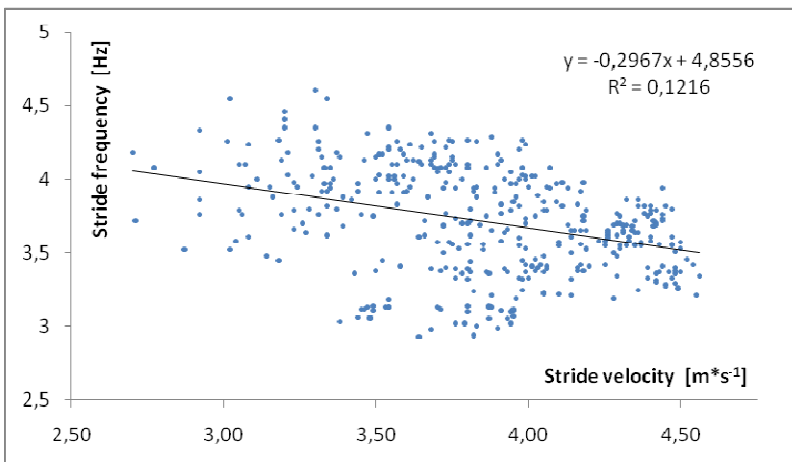


Chart 3 Relationship stride frequency and stride velocity in athletic walking

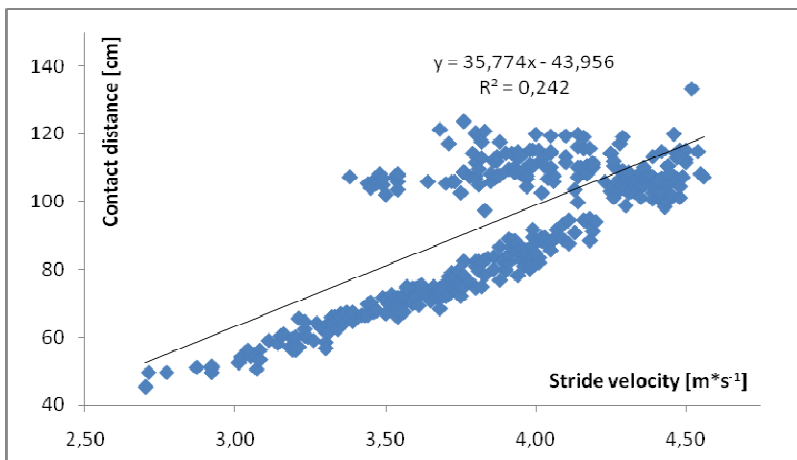


Chart 4 Relationship contact distance and stride velocity in athletic walking

Table 1 Differences in kinematic parameters of dominant and non dominant leg in a speed zone 4'25 - 4'15 min.km⁻¹

Indicators	The dominant lower leg		Non-dominant lower leg		Difference	
	\bar{x}	s	\bar{x}	s	d	t-test
Stride length [cm]	124,68	41,59	137,06	115,06	12,38	0,52
Contact time [ms]	291,64	123,55	341,40	313,90	49,76	0,781
Flight time [ms]	33,72	21,47	21,04	17,24	-12,68	2,238*
Contact distance [cm]	112,80	45,32	129,86	116,90	17,05	0,71
Flight distance [cm]	11,88	7,16	7,20	5,81	-4,67	2,459*
Stride velocity [m*s ⁻¹]	3,84	0,08	3,79	0,04	-0,05	3,899**
Contact velocity [m*s ⁻¹]	3,89	0,11	3,83	0,05	-0,07	3,187**
Flight velocity [m*s ⁻¹]	3,58	0,57	3,29	1,19	-0,29	0,97
Stride frequency [Hz]	3,30	0,72	3,39	0,91	0,08	0,429

(p<0,01** p<0,05*)

Table 2 Differences in kinematic parameters of dominant and non-dominant leg in a speed zone 4'10 - 3'55 min.km⁻¹

Indicators	The dominant lower leg		Non-dominant lower leg		Difference	
	\bar{x}	s	\bar{x}	S	D	t-test
Stride length [cm]	115,96	8,04	110,18	8,11	-5,78	2,193*
Contact time [ms]	253,52	29,91	243,16	28,37	-10,36	1,135
Flight time [ms]	27,52	13,14	27,56	13,11	0,04	0,012
Contact distance [cm]	105,07	11,62	99,23	11,41	-5,84	1,632
Flight distance [cm]	10,89	4,81	10,94	4,82	0,05	0,043
Stride velocity [m*s⁻¹]	4,13	0,06	4,07	0,06	-0,06	13,29**
Contact velocity [m*s⁻¹]	4,15	0,06	4,08	0,07	-0,07	6,025**
Flight velocity [m*s ⁻¹]	4,06	0,32	4,04	0,32	-0,02	0,2
Stride frequency [Hz]	3,58	0,25	3,71	0,26	0,14	1,58

(p<0,01** p<0,05*)

THE BIOMECHANICS OF EFFICIENT RACE WALKING

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Abstract

The aim of this study was to measure and assess the biomechanical efficiency of elite race walkers. Thirty-six athletes were videoed at four different points during the 7th European Cup Race Walking. Twelve of these athletes competed in the men's 20 km race, twelve in the women's 20 km race, and twelve in the men's 50 km race. Kinematic variables such as step length, pelvic rotation and knee angles were measured. Additionally, twenty-seven athletes (eighteen men and nine women) walked on a treadmill with in-built force plates in a laboratory setting. In this part of the study, variables of interest included impact force, propulsive force and base of support. Race walking utilised pelvic rotation and pelvic tilt much more than normal walking, due partially to fully straightened knees from contact to the vertical upright position. These pelvic movements also prevented the athletes' centres of mass from rising too high. Force trace analysis showed that senior athletes had more efficient and typical race walking patterns than junior athletes, which may be an indicator of less training experience. Analysis of the effects of fatigue showed that important variables such as step length changed over the course of the walk. The 50 km men had knee contact angles that decreased significantly with fatigue and were therefore more likely to be disqualified in the later stages of the race.

Introduction

Race walking was first introduced to the Olympic Games held in London in 1908 (Lassen, 1990), following its growth from 'pedestrian' races for cash wagers that became popular in 18th century Britain (Kozloff, 2004). Early Olympic races were held over various distances, particularly 10,000 m on the track, until 1956 when the 20 km race joined the 50 km race that had first appeared in 1932 (Marlow, 1990). Performances improved relatively steadily until large improvements started to occur with the emergence of the Mexican race walkers in 1968 (Lassen, 1990) who achieved great walking speeds through an exaggerated gait, such as walking with the feet in a

straight line and large pelvic rotations (Hopkins, 1978). Prior to this, race walking generally looked like normal walking but at a faster pace.

Although modern race walking is very much an exaggerated form of walking, there are similarities in the way efficiency in each is optimised. There are several optimisations of gait used to minimise vertical and side-to-side oscillation of the centre of mass during normal walking, as described by Inman *et al.* (1981). These are also known as the determinants of gait (Whittle, 1996) and two of the most important are pelvic rotation (in the transverse plane) and pelvic tilt (in the frontal plane). First, pelvic rotation is the manner in which the pelvis twists about a vertical axis, bringing each hip joint forwards as that hip flexes, and backwards with hip extension (Whittle, 1996). This results in less hip flexion and extension being required as part of the step length comes from the anteroposterior movements of the pelvis rather than through angular motion (Inman *et al.*, 1981). The motion also increases efficiency by reducing the vertical displacement of the centre of mass (Whittle, 1996). Second, pelvic tilt is the way the pelvis turns about an anteroposterior axis so that the hip of the swing leg is below that of the stance leg. The lowering of one side of the pelvis brings about an overall lowering of the centre of mass (Whittle, 1996). Pelvic tilt is therefore one of the main compensating mechanisms in race walking counteracting the negative effects of knee extension on the movement of the centre of mass (Polozkov and Papanov, 1982).

Effective control of the pelvic girdle is especially important in increasing race walking speed, because pelvic rotation increases walking velocity by eliciting greater step lengths (Murray *et al.*, 1983; Knicker and Loch, 1990). Frukto *et al.* (1984) suggested that the pelvic rotation increased both step length and step frequency as it allows additional muscle groups to be employed in the forward movement of the legs rather than just because of the greater range of movement (Trowbridge, 1981). Inman *et al.* (1981) stated that for typical people walking at their customary step frequency and step length, pelvic rotation is usually about 4° to each side (8° in total) but that the value increases noticeably with increased speed. Cairns *et al.* (1986) also found pelvic tilt to be increased in race walking compared to normal walking and running. Cairns *et al.* (1986) and Ruhling and Hopkins (1990) suggested that these pelvic movements minimised the vertical oscillations of the centre of mass through the stance phase and therefore reduced energy cost. This also helps to reduce the appearance of lifting (Villa, 1990). The

lateral drop of the pelvis away from the stance leg in the frontal plane was the primary cause for the decrease in centre of mass lift in the study by Cairns *et al.* (1986).

Rotation of the pelvic girdle furthermore allows for narrowing of the stride width and placing of the feet closer to the line of progression (Hopkins, 1978; Fenton, 1984). Indeed, an athlete consciously placing his or her steps in an almost straight line will achieve pelvic rotation easier (Schmolinsky, 1996). The stride width is also referred to as the base of support. Whittle (1996) stated that by keeping the base of support narrow, less lateral movement is needed to maintain balance and therefore a reduction in muscular energy is achieved. The base of support in normal walking is usually between 5 and 10 cm (Whittle, 1996), and was found to be 6.5 and 9.2 cm in two world-class race walkers respectively (Murray *et al.*, 1983). In addition, Markham (1989) stated that while in normal walking the toes point slightly outwards, in race walking the feet should point exactly forward. The aim of maintaining a straight foot during stance was to maximise step length and improve push-off.

One of the other main optimisations of normal gait is knee flexion at midstance but of course this is not an option available to race walkers. It is unclear in any case whether a bent knee during stance is an advantage or disadvantage to the athlete. For example, Knicker and Loch (1990) stated that there is no benefit in bending the knee at midstance because the increased loading on the knee would tire the quadriceps femoris quicker, and the increased vertical oscillation would increase energy cost. In contrast, Schmolinsky (1996) suggested that a bent knee at contact was of benefit as it reduces the braking effect of the foot landing ahead of the body. Despite this, and even before the rule requiring a straightened knee at contact, Hopkins (1978) stated that a straight knee at initial contact was common to most if not all world class walkers. Murray *et al.* (1983) and Cairns *et al.* (1986) claimed that this is because landing with an extended knee increases the distance the foot lands in front of the body and hence increases step length. Laird (2000) suggested that it is because flexed knees promote the use of the powerful quadriceps femoris muscle group and result in a running motion that they must be kept straight (running does feature a flexed knee throughout stance (Kersting, 1999)). Marchetti *et al.* (1982) stated that running is more efficient than race walking because running utilises stored elastic energy more through knee flexion.

Cairns *et al.* (1986) stated that the rules requiring straight knees results in a rising of the centre of mass and therefore an increase in vertical displacement through the stance phase. Vertical displacement during stance should be controlled and minimised as much as possible in order to avoid flight phases (Drake *et al.*, 2005). In normal walking, vertical displacement rises with increased walking speed and step length (Inman *et al.*, 1981). Murray *et al.* (1983) found that vertical displacement in two world class race walkers decreased from 4.1 cm when walking fast (but with a normal gait) to 2.8 cm when race walking. Murray *et al.* (1983) hypothesised that the reason for the unnatural-looking movements associated with race walking were a result of this decreased vertical displacement and its association with reduced energy cost. Knicker and Loch (1990) discovered that vertical displacement in five race walkers measured at multiple points in a 35 km race ranged from 0.02 to 0.07 m, with a mean of 0.04 m.

Aside from the stance phase, the knee is also of importance during the swing phase in reducing the moment of inertia of the leg and preparing it for initial contact. Hopkins (1978) wrote that Hausleber, the highly successful Polish coach of the Mexican race walkers, believed that a knee angle of 90° at the point of midswing was desirable in developing optimal pelvic rotation. Cairns *et al.* (1986) found maximum knee flexion during swing in ten competitive race walkers to be 108° (± 7), compared to 89° (± 11) during running at the same speed. Knicker and Loch (1990) measured the minimum swing knee angle (maximum flexion) in five male race walkers as between 87 and 108°, and this did not tend to vary within individuals with fatigue.

Previous research in race walking has predominantly focussed on kinematic data without reference to ground reaction forces (GRF). Payne (1978) measured the GRF for one international race walker and found only small increases in vertical and anteroposterior forces compared to normal walking. Fenton (1984) conducted studies on seven athletes of varying ability. Lower vertical impact peaks occurred in elite athletes compared to less skilled walkers. A weight-bearing peak then occurred, and a much smaller decrease in force to the point of midstance compared to normal walking. The final propulsive peak was smaller in race walking compared to normal walking as a proportion of the first peak (in race walking the propulsive peak was approximately 0.5 BW below the weight-bearing

peak). Cairns *et al.* (1986) found that the vertical ground reaction force (GRF) was significantly larger in race walking compared to normal walking, but significantly lower than running. Fenton (1984) found that force traces differed in appearance between those of elite competitors and those of less ability. This was despite all participants walking at the same speeds of 10.8, 12.1, 13.7, and 16.2 km/hr. Force trace patterns were similar across all speeds, and the main difference between the elite and non-elite walkers was the timing of the maximum vertical force: the slower group experienced this at the impact peak during the first 10-15% of stance, whereas the faster group experienced the maximum vertical GRF at the following weight-bearing peak, between 15 and 25% of stance. A third peak, approximately 0.5 BW lower than the peak force occurred in all athletes during the final 50% of stance and was thought to be lower due to the need to reduce vertical motion upon toe-off (Fenton, 1984). A typical vertical force trace from race walking is shown in Figure 1.

A limitation of measuring kinetic data by means of in-dwelling force plates is the difficulty with which multiple meaningful trials are possible. The accuracy of data collection can be affected by athletes targeting the force plates rather than walking naturally and ensuring that athletes walk at an appropriate, realistic pace. To combat this, Ávila *et al.* (1998) used a treadmill with in-built force plates (Gaitway, Traunstein) to compare normal walking GRFs with those in race walking; the four female athletes tested tended to display less variability in vertical forces when race walking. Neumann *et al.* (2008) used a similar treadmill to analyse four junior female race walkers at multiple points during a 6 and a 10 km walk, and found that the coefficient of variation for temporal variables tended to increase with distance walked. These studies focussed particularly on variability and not the importance of the kinetic parameters to race walking per se. Kinetic data collection has thus been negligible resulting in a lack of understanding of the mechanisms behind important kinematic parameters, particularly in women and junior athletes. There is thus a need for such research.

Race walkers and marathon runners have similar physiological profiles due to the similar aerobic endurance base needed for both events, although walking is much less efficient than running (Cairns *et al.* 1986). Previous research has shown that success in race walking is related more to the efficiency of technique rather than physiological factors (Hoga *et al.* 2003). Modifications in gait patterns may affect the energy cost of walking

(Brisswalter *et al.* 1998) which can be caused by fatigue. When the body is placed under immense physical pressure in competitive race walking, the body becomes subjected to the effects of fatigue. Athletes can normally continue performing whilst experiencing fatigue levels but their technique may alter (Brisswalter *et al.* 1998). These changes usually occur at the end of a race or within the final stages. This is especially important in race walking, where poor technique can lead to disqualification. Knicker and Loch (1990) conducted a study on the effects of fatigue on the gait parameters of 35 km walkers, although this was limited to five athletes, of whom only one participant was measured on more than two occasions. Nonetheless, they did conclude that step length decreased with race progression (from a mean of 1.17 m at 5 km to 1.12 m at 15 km) and that this decrease was related to a reduction in forward propulsion caused by the onset of fatigue. Brisswalter *et al.* (1998) found that although fatigue caused individual walkers to alter their gait in order to maintain speed, they managed to do so without breaking the rules specific to race walking. The altering of kinematic variables during competition will affect physiological output (and vice versa).

Gait optimisations, such as pelvic tilt and a narrow base of support, are crucial for minimising energy cost in race walking. Frukto^v *et al.* (1984) suggested that once the technical parameters of race walking have been established and corrected, technique is improved by eliminating vertical and sideways movements through using these optimisations. The aim of this study was to measure and assess the biomechanical efficiency of elite race walking gait. The objectives of the study were to collect video data of race walkers in international competition, to collect force data of elite race walkers in a laboratory-based study using a specialised treadmill, and in each case, observe the effects of fatigue on these data. The findings will be of particular relevance to coaches and athletes wishing to improve their chances of competitive success.

Methodology

For this study, data were collected in two separate ways. First, video data were collected in order to measure kinematic variables such as pelvic rotation, pelvic tilt, and angles of the knee. Second, kinetic data in the form of force measurements were collected using a specialised treadmill.

1. Video study

The men's and women's 20 km races as well as the men's 50 km race were recorded at the 7th European Cup Race Walking held in Royal Leamington Spa, Great Britain in 2007. The 20 km athletes were filmed as they passed 4.5, 8.5, 13.5, and 18.5 km, while the 50 km men were filmed as they passed 18.5, 28.5, 38.5, and 48.5 km. Twelve 20 km men (age 25 ± 4 years, height 1.80 ± 0.06 m, mass 67 ± 5 kg), twelve 20 km women (age 25 ± 5 years, height 1.64 ± 0.07 m, mass 52 ± 6 kg) and twelve 50 km men (age 28 ± 6 years, height 1.81 ± 0.07 m, mass 67 ± 4 kg) were analysed.

Participants' heights, masses and dates of birth were obtained from the International Association of Athletics Federations (IAAF) (2009). In each race, athletes who were obscured by other competitors, did not walk through the set reference area, or who were not walking normally at the time (e.g. wiping their brow) were not analysed. None of the analysed athletes were disqualified or failed to complete the race.

Two stationary DM-XL1 digital camcorders (Canon, Tokyo) were placed on one side of the course. The cameras were mounted on rigid tripods and placed at approximately 45° and 135° respectively to the plane of motion; each camera was approximately 8 metres from the path of the walkers. The sampling rate was 50 frames per second and the shutter speed $1/500$ s. The reference volume was 5.00 m long, 2.00 m wide and 2.16 m high. The reference poles were filmed both before and after data collection in case of camera movement. They were placed so that the 2 m width coincided with the path taken by most walkers (along the shortest possible route at that point).

The video data were digitised to obtain kinematic data using motion analysis software (SIMI, Munich). The video footage from each camera was synchronised manually by visual identification of multiple simultaneous events (i.e. initial and final foot contact). De Leva's (1996) body segment parameter models for males and females were used to obtain centre of mass data for the whole body and particular limb segments. Joint angular data were also derived from the digitised body landmarks. The recordings were smoothed using a cross-validated quintic spline. The results for each side of the body were averaged for the purposes of this study.

2. Force study

Twenty seven national and international race walkers gave informed consent and the study was approved by the university's ethics committee. Of the athletes, fifteen were 20 km walkers. Ten were male (age 26 ± 8 years, height $1.79 \pm .06$ m, mass 71.7 ± 6.8 kg) and five were female (age 22 ± 4 years, height $1.67 \pm .04$ m, mass 53.0 ± 8.1 kg). The other twelve walkers were juniors and comprised eight men (age 17 ± 1 years, height $1.79 \pm .06$ m, mass 64.0 ± 12.0 kg) and four women (age 17 ± 1 years, height $1.67 \pm .03$ m, mass 58.3 ± 4.8 kg). All participants were free from injury. Each senior athlete who normally raced over 20 km or 50 km walked for 10 km on a treadmill (Gaitway, Traunstein) at a pace that resulted in a walking time equivalent to 105% (± 2) of their season's best time. Junior athletes who normally raced over 10 km walked on the treadmill for 5 km. Each athlete walked at a constant pace for the duration of the test.

Force data were recorded using the Gaitway treadmill, which has two indwelling force plates (Kistler, Winterthur). Data were collected for thirty seconds and the sampling rate was 1000 Hz. This resulted in analysis of approximately 90 to 100 steps per athlete at each sampling point. Data were collected three times during the 5 km walks and four times during the 10 km walks. Data collection began at a calculated time that resulted in the midpoint of data collection coinciding with 1000 m, 2500 m, and 4500 m (for the 5 km walkers) and 2500 m, 4500 m, 6500 m and 8500 m (for the 10 km walkers).

The Gaitway software produced average data for important force variables. In order to account for the different body sizes of the walkers, all force data were normalised and have therefore been presented here in bodyweights (BW). As well as force data, the associated software gave values for step length and base of support.

Overall study

Walking speed was determined as the average horizontal speed during one complete gait cycle (two steps). Step length was measured as the distance the body travelled between a specific phase on one leg and the same phase on the other leg.

Definitions of specific reference points used in this study are as follows:

- Initial contact: the first visible point during stance where the athlete's foot clearly contacts the ground.
- Toe-off: the last visible point during stance where the athlete's foot clearly contacts the ground.
- Midstance: the point where the athlete's foot was directly below their body's centre of mass, used to determine the 'vertical upright position' (IAAF Rule 230.1).

Pearson's product moment correlation coefficient was used to find associations in both the European Cup video data and the treadmill force data. Because of low sample sizes for each specific event and gender group, Pearson's coefficient was used to find associations within all walkers in the European Cup ($N = 36$) and all walkers who were tested on the treadmill ($N = 27$). Because the athletes were measured on multiple occasions, the correlations have only used those data from approximately halfway in each race (8.5 km for the 20 km athletes, 28.5 km for the 50 km athletes) and also from approximately halfway for the treadmill athletes (4500 m for the senior athletes and 2500 m for the juniors). Repeated measures analysis of variance was conducted on both sets of data recorded at multiple points with repeated contrast tests conducted to establish significant changes between successive measurement points. One-way ANOVA was used to test differences between 20 km men, 50 km men and 20 km women in the European Cup. A significance level of 0.05 was set for all of these tests.

Results

The mean values presented in Table 1 show a decrease in speed over the course of all three races. The greatest decrease for the 20 km men occurred between 4.5 km and 8.5 km (0.39 km/hr), while the greatest reductions for the 20 km women (0.45 km/hr) and 50 km men (0.55 km/hr) were between the second-last and final measurement points. Overall reduction in speed over the course of the 20 km men's race was 0.64 km/hr, for 20 km women 0.92 km/hr, and for 50 km men 0.68 km/hr. The decrease in speed in all races was significant ($p < .01$).

Table 2 shows that the largest mean step length for each set of athletes was observed during the first stage of analysis, and gradually decreased to its lowest level towards the end of the race. The decrease in both sets of men's step lengths was significant ($p < .01$) but the women's decrease was not ($p = .127$), despite it being the largest decrease in absolute terms. Speed was correlated with step length ($r = .812$, $p < .001$) and Figure 2 shows the correlation between step length and speed for all thirty-six participants.

The pelvic rotation angles in Table 3 are horizontal plane measurements of the pelvis associated with race walking. The rotation values are the averages to each side (i.e. the average of rotation to the right and rotation to the left). Although women in general have wider hip structures, the results show that hip rotation averages were in fact lowest in this group and highest in the 20 km men. The values for women were constant and did not change significantly with fatigue ($p = .701$) whereas the decrease in hip rotation in both groups of men was significant ($p < .01$). Increased hip rotation was correlated with greater step lengths ($r = .775$, $p < .001$) and speed was also positively correlated with pelvic rotation ($r = .565$, $p < .001$).

The second gait optimisation, pelvic tilt, is shown in Table 4. Similarly to pelvic rotation, the values in the women's group were relatively constant with no significant differences ($p = .281$). The increase from 7° to 11° in the 20 km men's group was significant ($p < .001$). Although it was only a small increase from 15° to 16° in the 50 km men's group, this change was nonetheless statistically significant ($p = .015$).

Table 5 shows the average knee angles at initial contact. The knee angle was calculated using the coordinates of the hip, knee and ankle joints. Taking into consideration all four measurement points, the range of values for 20 km men at initial contact was between 173° and 184° ; for 50 km it was between 175° and 183° , while for women it was between 175° and 184° . There were no significant differences between men and women for any of these knee angle variables and there were no significant correlations between knee angles at contact with any other variables. Furthermore, the values for knee angle did not change significantly with fatigue. Knee hyperextension was considered to occur when the knee was extended more than 180° . On average, the 20 km men had hyperextended knees for 71% (± 16) of contact time, the 50 km men for 49% (± 21) and the women 70% (\pm

6). These values showed the 50 km men spent significantly less time in hyperextension than either 20 km group ($p = .002$).

The values for the knee angle during swing, the highest and lowest position of the foot during swing, and the rise of the centre of mass for each group of athletes are shown in Table 6. Only one set of data are shown per group (the halfway point rather than the repeated measurements) because there was no significant differences between measurement points. Swing phase knee angle was defined as the amount of maximum knee flexion during the swing phase (the lower the figure, the more bent the knee). The women had significantly more flexion than the two male groups ($p = .005$). The height of the foot is usually kept low in race walking to prevent the appearance of lifting and to aid the foot to contact the ground again as quickly as possible. The foot follows a pattern during swing where it is lifted to a maximum height after toe-off before swinging low near to the ground (the minimum height). It then swings back up higher prior to being pulled back at initial contact. The maximum height of the foot during swing did not differ between groups of athletes, but the 50 km men had a significantly lower minimum height ($p = .002$). The minimum height of the foot was correlated negatively with pelvic tilt angle ($r = -.351, p = .036$).

A major function of the optimisations of gait is to minimise the rise of the centre of mass of the whole body, which would be expected to rise significantly due to the absence of knee flexion. The rise of the centre of mass was determined as the difference between the lowest and highest points during the gait cycle. However, the highest point occurred in all cases immediately following toe-off rather than at midstance.

Because it is a very small quantity, base of support was measured in a separate study using force plates inbuilt in a treadmill to improve accuracy. Tables 7 and 8 show the walking speed, step length, and base of support for the athletes who were tested in this part of the study. The athletes did not walk at their maximum speed on the treadmill and so their average values are slower than those from the European Cup video study. Speed was positively correlated with step length ($r = .829, p < .001$). Base of support was slightly lower for both sets of juniors compared to seniors, with senior women having the largest base of support on average. There was no correlation between base of support and either speed ($r = -.144, p = .475$) or step length ($r = -.197, p = .326$). The other kinematic variable measured

using the treadmill was the angle of the foot during stance. This was measured using the progression angle, which gives a value that indicates if the foot is turned inwards (a negative value) or outwards (a positive value). Using the data from the halfway-point measurements, inward-turned feet were found in four of the ten senior men, all five senior women, four of the eight junior men and two of the four junior women. There were large variations, however, with inward feet measurements ranging from less than one degree to nearly 14° . Although there was also a sizeable range with the out-turned feet, it was not as great, from less than one degree to just over 7° .

An advantage of the force data is that they allow for analysis of relevant variables which cannot be measured on video. Tables 9 and 10 show the results for the impact peak forces, as well as first and second peaks. Impact peak was defined as the highest recorded force during the first 70 ms of contact with the treadmill; midsupport force was defined as the minimum force value recorded between the first (weight-bearing) and second (propulsion) peak forces. All forces are shown as normalised data. Both senior and junior men had lower impact peaks, first peak forces, and midsupport forces than senior women. In contrast, senior women had the lowest values at the second peak during push-off. In general, the largest decreases from first peak to second peak forces were found in senior men (approximately 0.17 BW averaged over the repeated measurements) and senior women (approximately 0.31 BW on average). The decrease in junior men was marginally lower than in seniors (0.15 BW on average) but much lower in junior women (0.03 BW on average).

None of these variables was correlated with key performance variables such as speed and step length. Impact forces remained relatively constant throughout the walks for both the senior and junior athletes. First peak forces decreased as the walks progressed in the senior walkers, although this decrease was not replicated in the juniors, and was not significant. Although overall second peak forces decreased during the walks, no significant differences were found for these variables.

Conclusions

The development and maintenance of efficient gait is crucial in the unique gait of race walking. Success in competitive race walking requires high

levels of both technical ability and physical endurance. Any inefficiency in a race walker's gait will increase energy cost and the risk of early fatigue. Reducing those inefficiencies greatly improves an athlete's chances of success, particularly in the men's 50 km event. The aim of this study was to measure gait optimisations that increase efficiency and the effects of fatigue on those factors.

Both groups of men achieved higher walking speeds compared to women due to their longer steps (mainly due to being taller on average). It is therefore obvious that maximising walking speed through gait optimisations such as pelvic rotation and minimising the base of support is crucial for coaches and athletes to develop in training. Pelvic rotation is particularly important in race walking. The values found in this study (approximately 14° for women; approximately 20° for men) were much greater than those found in normal walking of 4° by Inman *et al.* (1981). The fact that men had more pelvic rotation than women may have been due to the men being taller with wider frames. It is possible that women do not require as much pelvic rotation as men because their hips are narrower in absolute terms and equal levels of rotation would result in their feet landing too far across the walking line. The amount of rotation required is different for each individual and coaches should aim for optimum rotation rather than maximum.

Another important gait optimisation, pelvic tilt, occurs in normal walking but is especially noticeable in race walking. Pelvic tilt was found to be the primary cause for the decrease in centre of mass lift in Cairns *et al.*'s (1986) study. The drop amongst the European Cup participants in the present study ranged from 7° to 16° across the three groups and so appears to be a highly developed characteristic of all race walkers. Dropping the hip so far in normal walking is considered negative as it is a sign of weak hip muscles; therefore its usefulness in race walking must be trained in order to maximise its effectiveness.

One reason for the relatively large amounts of pelvic tilt is its role in compensating for the lack of knee flexion in the stance leg. In normal walking, knee flexion during stance aids in efficient walking. In contrast, the main concern of the race walker is to have it straightened from contact to midstance and the result is a gait that is quite separate from normal walking or running. The data from the video study showed that men and

women had on average full or nearly full extension of the knee at initial contact. Rather than experiencing the knee flexion that occurs during midstance in normal walking, these race walkers instead hyperextended their knees. There was no difference found in the angle of the knee at initial contact between groups of athletes, which is not surprising as all walkers attempt to straighten the knee at this point. However, it is noteworthy that the 50 km athletes had slightly reduced knee angles at 48.5 km, which is an effect of fatigue that must be addressed to avoid disqualification in the latter stages of the race.

The angle of the knee during the swing phase showed an average value for women of 97° , for 20 km men of 102° , and for 50 km men of 101° . These values fit into the range of 87 to 108° found by Knicker and Loch (1990) but none of the athletes reached the recommended figure of 90° as recommended by Hausleber (Hopkins, 1978). The lowest figure was 92° for a female athlete. Like Knicker and Loch (1990), this study did not find the swing knee angle changed with fatigue. The angle of the knee during swing affects the height of the foot, and the average value of 10 cm is very low and unlikely to attract the attention of judges. In contrast, the highest points of the foot are just after toe-off and in preparation for contact, and athletes must be careful to try to maintain a low passage of the foot to avoid lifting. As it happened, the rise of the centre of mass was very small for all athletes.

The base of support measurements from the force study showed an average measurement of approximately 3 cm for junior athletes and 4 cm for seniors. These values are lower than the normal range of 5 to 10 cm as suggested by Whittle (1996) and are a characteristic of race walking. The foot should be kept straight during the stance phase of race walking to increase step length (Markham, 1989) but the results from the treadmill study showed that just under half of the athletes had out-turned feet (although these angles did tend to be quite small). In contrast, some athletes had a very large amount of turning-in which may have negative consequences in terms of propulsion and lower leg injury. Coaches should try to ensure that athletes achieve the correct foot position through visual analysis.

In the force data study, the impact peaks for both senior and junior men were lower compared to both groups of women. This may suggest that the male athletes were more skilled than the females, as suggested by Fenton (1984). The men had an overall greater mean age and this may reflect more

training experience. Midsupport forces in normal walking tend to drop below 1 BW; a range between 1.19 and 1.40 BW was found here. Furthermore, all groups had lower propulsive second peak values than loading first peaks, and the largest decrease was 0.31 BW. This value is less than that found by Fenton (1984) who found a 0.50 BW decrease, but the overall vertical force pattern suggested by him was mostly replicated here. The junior women showed the smallest decrease between these two values, and this may be a result of their relative inexperience in the event. Both groups of senior athletes showed relatively typical race walking GRF patterns in an attempt to prevent lifting of the centre of mass. Typical race walking patterns are not shown in less-experienced junior athletes. Coaches and athletes are advised to develop muscular endurance and work towards developing efficient race walking gait in order to develop efficiency of movement and reduce the risk of disqualification due to lifting.

Race walking is a highly technical event in which the competitor must perform a specific skill continuously. Training for success requires consideration of many factors and the ability of the athlete to develop all the aspects of strength, flexibility, and endurance. The optimisation of race walking performance depends greatly on balancing a number of key parameters. Once an athlete has mastered these variables, the limiting factor becomes endurance and the resulting ability to maintain technique. Because race walking rules prohibit knee flexion until after the vertical upright position, other determinants of gait such as pelvic tilt are exaggerated to compensate. Elite race walkers also increase pelvic rotation to increase step length and speed. They have knee joint actions that allow them to walk in an extremely efficient straight line. All athletes, and especially 50K men, should note that technique deteriorates with fatigue to the point where there is an increased risk of disqualification. The effects of fatigue may be offset by walking at a constant pace throughout the race.

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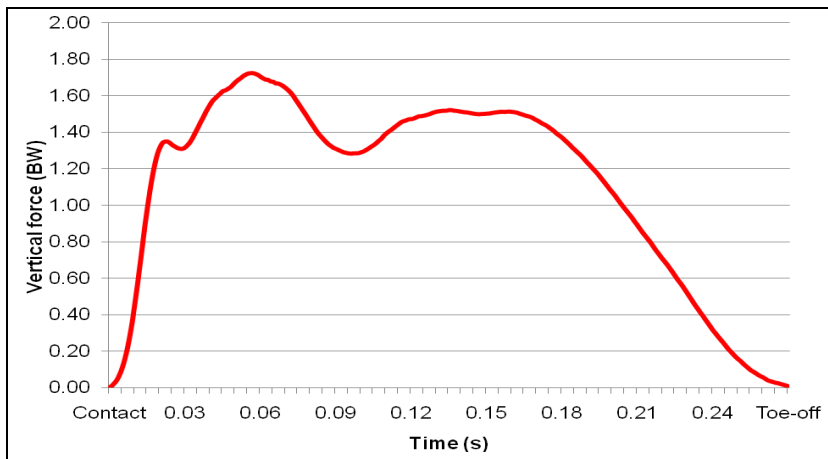


Figure 1. A race walking vertical ground reaction force trace. A distinctive impact peak is followed by a weight-bearing peak, midstance, and a final propulsive peak.

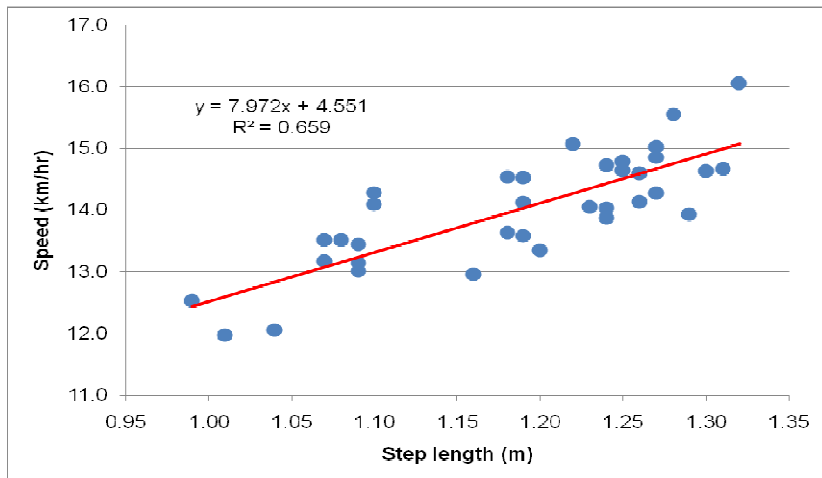


Figure 2. The relationship between speed and step length for all thirty-six competitors.

Table 1. Video study - Speed at each stage of analysis (mean \pm SD)

	Distance	20K Women	20K Men	Distance	50K Men
Speed (km/hr)	4.5 km	13.55 (\pm 1.21)	15.12 (\pm 0.53)	18.5 km	14.11 (\pm 0.61)
	8.5 km	13.20 (\pm 0.72)	14.73 (\pm 0.63)	28.5 km	14.15 (\pm 0.60)
	13.5 km	13.08 (\pm 0.77)	14.66 (\pm 0.79)	38.5 km	13.98 (\pm 0.76)
	18.5 km	12.63 (\pm 1.03)	14.48 (\pm 0.95)	48.5 km	13.43 (\pm 0.71)

Table 2. Video study - Step length at each stage of analysis (mean \pm SD)

	Distance	20K Women	20K Men	Distance	50K Men
Step length (m)	4.5 km	1.10 (\pm .08)	1.27 (\pm 0.02)	18.5 km	1.25 (\pm 0.05)
	8.5 km	1.07 (\pm .05)	1.24 (\pm 0.04)	28.5 km	1.24 (\pm 0.04)
	13.5 km	1.07 (\pm .05)	1.24 (\pm 0.03)	38.5 km	1.23 (\pm 0.05)
	18.5 km	1.05 (\pm .07)	1.24 (\pm 0.04)	48.5 km	1.20 (\pm 0.05)

Table 3. Video study - Pelvic rotation at each stage of analysis (mean \pm SD)

	Distance	20K Women	20K Men	Distance	50K Men
Rotation ($^{\circ}$)	4.5 km	14 (\pm 2)	18 (\pm 3)	18.5 km	21 (\pm 3)
	8.5 km	14 (\pm 3)	21 (\pm 3)	28.5 km	19 (\pm 2)
	13.5 km	14 (\pm 2)	22 (\pm 3)	38.5 km	18 (\pm 3)
	18.5 km	15 (\pm 3)	22 (\pm 2)	48.5 km	17 (\pm 3)

Table 4. Video study - Pelvic tilt at each stage of analysis (mean \pm SD)

	Distance	20K Women	20K Men	Distance	50K Men
Tilt ($^{\circ}$)	4.5 km	12 (\pm 1)	7 (\pm 2)	18.5 km	15 (\pm 1)
	8.5 km	11 (\pm 2)	8 (\pm 1)	28.5 km	15 (\pm 1)
	13.5 km	12 (\pm 1)	10 (\pm 1)	38.5 km	15 (\pm 1)
	18.5 km	12 (\pm 1)	11 (\pm 1)	48.5 km	16 (\pm 1)

Table 5. Video study - Knee contact angle at each stage of analysis (mean \pm SD)

	Distance	20K Women	20K Men	Distance	50K Men
Angle ($^{\circ}$)	4.5 km	180 (\pm 2)	179 (\pm 3)	18.5 km	179 (\pm 2)
	8.5 km	180 (\pm 2)	179 (\pm 3)	28.5 km	179 (\pm 2)
	13.5 km	180 (\pm 2)	180 (\pm 3)	38.5 km	180 (\pm 2)
	18.5 km	180 (\pm 3)	179 (\pm 2)	48.5 km	178 (\pm 3)

Table 6. Video study – Knee swing angle, foot position, and rise of the centre of mass at approximately halfway (mean \pm SD)

	Knee swing ($^{\circ}$)	Foot max. height (m)	Foot min. height (m)	Rise of the CM (cm)
20 km Women	97 (\pm 4)	0.18 (\pm .01)	0.10 (\pm .01)	0.05 (\pm .01)
20 km Men	102 (\pm 4)	0.19 (\pm .01)	0.11 (\pm .01)	0.06 (\pm .01)
50 km Men	101 (\pm 4)	0.18 (\pm .01)	0.09 (\pm .01)	0.05 (\pm .01)

Table 7. Force study – Speed, step length, and base of support in junior athletes (mean \pm SD)

Distance	Speed (km/hr)	Step length (m)	Base of support (cm)
Junior men			
1000 m	11.92 (\pm .83)	1.09 (\pm .06)	3.0 (\pm 1.7)
2500 m	11.92 (\pm .82)	1.09 (\pm .06)	3.1 (\pm 1.3)
4500 m	11.91 (\pm .82)	1.08 (\pm .07)	3.1 (\pm 1.1)
Junior women			
1000 m	10.97 (\pm .62)	0.98 (\pm .04)	2.8 (\pm 1.4)
2500 m	10.97 (\pm .64)	0.98 (\pm .05)	2.8 (\pm 1.4)
4500 m	10.97 (\pm .65)	0.99 (\pm .06)	2.8 (\pm 1.5)

Table 8. Force study – Speed, step length, and base of support in senior athletes (mean \pm SD)

Distance	Speed (km/hr)	Step length (m)	Base of support (cm)
Senior men			
2500 m	12.68 (\pm .54)	1.14 (\pm .07)	3.7 (\pm 2.7)
4500 m	12.67 (\pm .54)	1.15 (\pm .07)	3.9 (\pm 2.7)
6500 m	12.67 (\pm .53)	1.15 (\pm .08)	3.7 (\pm 2.6)
8500 m	12.67 (\pm .54)	1.15 (\pm .07)	4.1 (\pm 2.6)
Senior women			
2500 m	11.65 (\pm .68)	1.02 (\pm .06)	4.0 (\pm 2.1)
4500 m	11.64 (\pm .67)	1.03 (\pm .06)	3.9 (\pm 2.3)
6500 m	11.65 (\pm .65)	1.03 (\pm .05)	3.9 (\pm 2.2)
8500 m	11.65 (\pm .65)	1.03 (\pm .06)	3.9 (\pm 2.5)

Table 9. Force study – Impact, 1st and 2nd peaks, and midsupport forces in junior athletes (mean \pm SD)

Distance	Impact (BW)	1st peak (BW)	Midsupport (BW)	2nd peak (BW)
Junior men				
1000 m	1.43 (\pm .14)	1.76 (\pm .13)	1.30 (\pm .28)	1.60 (\pm .08)
2500 m	1.45 (\pm .16)	1.78 (\pm .12)	1.37 (\pm .31)	1.63 (\pm .09)
4500 m	1.42 (\pm .18)	1.77 (\pm .11)	1.38 (\pm .29)	1.62 (\pm .09)
Junior women				
1000 m	1.53 (\pm .19)	1.68 (\pm .10)	1.28 (\pm .20)	1.68 (\pm .03)
2500 m	1.55 (\pm .22)	1.71 (\pm .11)	1.30 (\pm .25)	1.67 (\pm .03)
4500 m	1.52 (\pm .21)	1.71 (\pm .14)	1.32 (\pm .27)	1.65 (\pm .05)

Table 10. Force study – Impact, 1st and 2nd peaks, and midsupport forces in senior athletes (mean \pm SD)

Distance	Impact (BW)	1st peak (BW)	Midsupport (BW)	2nd peak (BW)
Senior men				
2500 m	1.43 (\pm .20)	1.73 (\pm .13)	1.25 (\pm .31)	1.56 (\pm .13)
4500 m	1.43 (\pm .20)	1.73 (\pm .12)	1.24 (\pm .32)	1.55 (\pm .14)
6500 m	1.41 (\pm .27)	1.71 (\pm .13)	1.24 (\pm .33)	1.54 (\pm .13)
8500 m	1.41 (\pm .18)	1.69 (\pm .10)	1.19 (\pm .30)	1.52 (\pm .13)
Senior women				
2500 m	1.45 (\pm .37)	1.83 (\pm .23)	1.37 (\pm .39)	1.54 (\pm .09)
4500 m	1.51 (\pm .40)	1.85 (\pm .24)	1.40 (\pm .38)	1.54 (\pm .09)
6500 m	1.50 (\pm .27)	1.84 (\pm .23)	1.38 (\pm .38)	1.51 (\pm .11)
8500 m	1.51 (\pm .42)	1.82 (\pm .25)	1.36 (\pm .41)	1.51 (\pm .12)

THE MODERN INSTRUMENTS OF KINEMATIC AND KINETIC TECHNIQUE EVALUATION AT THE COMPETITORS PRACTICING RACE WALKING

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Abstract

Contemporary sport requires interdisciplinary cooperation. Norms are the scientists from different scientific areas cooperating with the coaches. Race walking is the only athletic endurance event, in which technique is assessed by the judges, that is why the information about movement biomechanics, which is used by coach to work on optimal and effective technique, is very important. In the presented work the authors undertook the presentation of methods and directions of research in Movement Biokinetic studio at Academy of Physical Education in Krakow Academy. The research possibilities in the following scope have been presented: three-dimensional race walking kinematic, complex evaluation of competitor's motor condition, ground's reaction force analysis, COM position change evaluation and muscle work, changes of angles, speeds and angular accelerations in joints, movement trajectories of osseous points and joints axis. The presented research methods and opportunities have been based on rich, own research material.

Key words: biomechanics, three-dimensional analysis, Vicon system, graphical record of electric currents associated with muscle contractions, ground reaction force, race walking.

Introduction

The race walking is periodical movement which is divided into two phases: support and wave. In the support phase both amortization and rebound can be specified. In the wave phase it is acceleration and braking. The walking paste is the function of length and frequency of the step which

are dependent on race walker's structure of the body and movement technique (Chwała 2009).

Biomechanical researches related to race walking technique include kinematics of race walker's movement. The most interesting literature positions which bring up various aspects of this discipline in the past years are Hagberg and Coyle (1984), Cairns and co. (1986). Hog and co. (2006), Yoshida (1989). The domination of kinematic analysis is the movement description with biomechanical variables without going into the cause of its origin. Kinetics concentrates on detailed search of movement, causes and description of internal and external forces competitor's interaction and gravitational field in which he/she moves about. (Ruchlewicz and co. 2006). The oscillation evaluation of general centre of body gravity determined with COM is quite significant in the movement technique analysis. It is a certain hypothetical but representative point for the whole body movement, where resultant of all gravity force acts at particular body segments of the competitor. The spatial movement COM evaluation allows to asses the changes of potential and kinetic energy, by further rotation machine-work done by competitor's movement system. The estimate of COM position changes could be done on the basis of ground's reaction force value registration in the phase where competitor's feet have contact with the ground, also the moments of body segments inertness and the change of their mutual position during the movement. Therefore both the kinematic and kinetic methods of evaluation allow to describe the characteristics of COM movement. Assessing COM movement we can conclude indirectly about the competitor's all body movement. (Chwała 2009).

In the area of kinematic movement parameters, there is analysis describing spatial movement, linear and angular velocity and body segments acceleration represented by their centres of gravity and joints' biomechanical axis. With regard to COM onward movement and rotary movement in the competitor's axis joints both the onward and rotary movement parameters are used to describe the movement. (Allard and co. 1997).

The other important aspect of kinematic evaluation is the intersegmental angle change analysis and angles enclosed between body segments and spatial coordinate system related to moving competitor's body, or immobile coordinate system connected with the ground. Like in

case of of segments and joints, the position changes are accompanied by the evaluation of velocity and acceleration of angular changes in joints.

The next area of kinematic analysis is the evaluation of work form, range of length changes, diagram of joining skeletal muscle propelling complex systems of osseous lever. It allows to estimate both functional biopotential values, muscle activity stage (EMG analysis), and observation of spatial distances changes between their muscle insertions. These allow to determine if the muscle takes part in joint stabilization, to do concentric work and see if during the active contraction their muscle insertions recede (eccentric work).

The domain of kinetic analysis is mutual interaction evaluation between muscle strength values, bond forces, and external forces such as body weight, ground reaction force, atmospheric centre resistance force or inertial force.

What's important from COM movement evaluation point of view is the external forces analysis, which determines this movement. Internal forces may only mutually change the position of body segments, but they do not change COM movement track.

Race walking three-dimensional kinematic analysis

The coaches, for the movement technique analysis, normally reach for race walking technique video recorded during the competition or training. (Hanley in al. 2008a,b). Due to little accuracy of such analysis it has the limited diagnostic value. The two-dimensional analysis, frequently done based on material registered with one digital camcorder can be insufficient for quantitative evaluation of race walking kinematics. What has significant influence on the accuracy of conducted analysis is the deformation of the registered body segments' linear diameters resulting from perspective phenomenon. Also picking up a technical error is often connected with the need of searching mutual movement interactions of body segments at all three levels. (Chwała and Maciejasz 2009).

The highly qualified contemporary sport requirements, oriented on movement economisation, force to use more sophisticated, complex evaluation methods of movement technique, which are capable of providing coach the precise information, which is later used to correct the technical errors and improve the sport result. They can also be used to locate

overloaded links of motion organ and to prevent the injuries effectively. (Chwała and Mirek 2009).

Because the race walking, which is a part of cyclical movement, has three-dimensional character, that is why the variables analysis determining technique should be done in three dimensions. In recent years measuring apparatus sets are used for this purpose, based on active and passive markers localized in essential antropometric points of the body, which permit the three-dimensional visualization of the registered movement.

One of the accurate reference systems, for the 3D analysis is the Vicon (Polygon User Manual 1998-2000) system. The research conducted during the past few years at Academy of Physical Education in Krakow, based on this system, allowed to accumulate rich research material, presented in few publications, amongst the race walkers group at the high sport championship level. (Chwała and co. 2005, 2007, 2009).

The system is created by the set of cameras, equipped in luminescent diodes (fig.1.), and the data station, where the information from the particular cameras is sent. The cameras work on borderland of visible light wave and infrared, and the image recording speed depends on settings and the camera type. The work frequency of used cameras is from 120 to 240 frames per second. Each and every camera records two-dimensional image, which is then sent to Datastation, where the images from the remaining cameras are analysed, and consequently creating three-dimensional image mapping of markers spatial location, that are stuck on the studied competitor's skin.



Fig. 1. The MX series modern cameras used in the Vicon Peak system (source: Vicon Polygon. (2002) Multi-media report, authoring tool for movement analysis, Vicon Motion Systems).

One of the measurement experiment elements is to execute anthropometric measurements of competitor's body, which can later, whilst modeling the movement, be used to recreate spatial skeleton model with the characteristic osseous points, axis joints and the muscle insertion points to the bone. With this end in view it is important to obtain the measurements concerning pelvis' width, knee-joints, tibial ankle joints, cubital joint, radial wrist joints, feet and arms thickness and relative length of competitor's lower limbs.

Before completing the measurement experiment it is essential to prepare the system and measurement space that is camera's working area where the race walking will be recorded. The cameras arrangement should provide good visibility of markers, which are on the examined person's body, and their work range should cover long enough area of walking path. Three-dimensional track image of particular markers movement is reached when each of them is registered in the same time by at least two cameras situated in different measurement space areas. (fig. 2.)

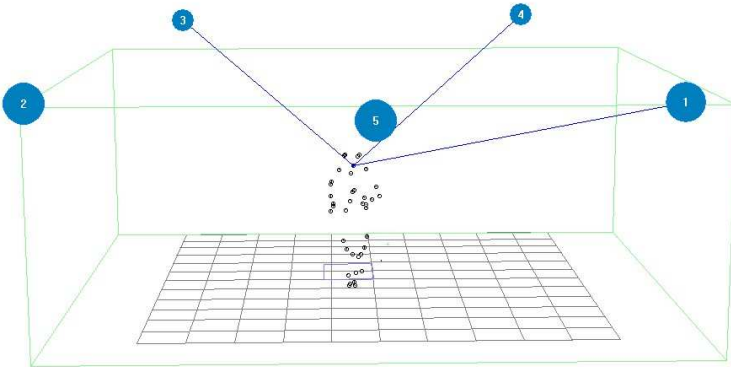


Fig.2 The measurement area of race walking recording with cameras localization and view of markers position (source: own research).

System calibration, which proceeds in two stages and has significant influence on measurement accuracy, is the next element of experiment preparation. Static calibration provides the information to a system about spatial orientation of coordinate system related to the ground. The second calibration's stage is distance evaluation between the markers in measurement space. It allows the recording optimization and markers recognition on the screen with specific coefficient of signal intensification. As a result of dynamic calibration the measurement system remembers the position of the markers in various space fragments and determines precisely the distances between them.

In order to begin the research it is essential to prepare the race walker in advance by sticking passive markers on the body and footwear. With regard to significant body segments' acceleration, markers occurring during walking are fixed with special tape that allows marker's movement to a point on the skin during the measurement experiment. Their layout reflects biomechanical body model scheme fig.3. They are fixed in joints' axis, in an appropriate distance from joints' symmetry centre and in characteristic points on head, chest, pelvis and foot. Thanks to this activity the spatial presentation of these body segments and gaining information about dimensions of particular body segments, such as chest range, pelvis, limbs and head sizes is possible.

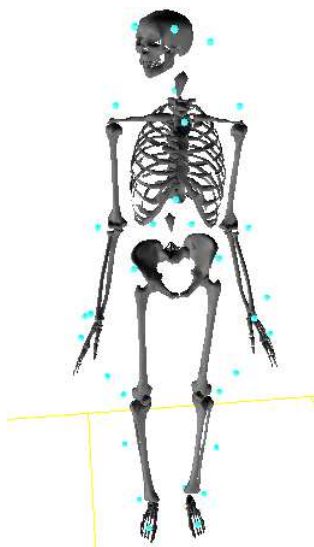


Fig.3. The set of whole body markers – view from the front (source: own research)

The Golem markers set has been used on examined race walkers. The trunk's coordinate system axis are determined by torso markers (C7, CLAV, TH10, STRN). The front head markers (LFHD and RFHD) define head's beginning and scale, where the back head markers (LBHD RBHD) determine its position in space. The pelvis coordinate system axis are determined by the pelvis markers (LASI, RASI) together with sacrum markers. The sacrum marker should reflect the natural anteversion of pelvis and should be located on perpendicular surface to the line joining the markers (LASI i RASI). It's very important to place both the markers in knee joints axis and markers in the foot area correctly.

The movement recording is the next stage, it can proceed in many stages, including speed of movement diversity, resulting from actual motoric condition of the competitor or the start distance. The race walking is also registered on treadmill, it enables to carry out the technique analysis with the given walking speed or the ground's angle of depression. Normally several dozen of race walking cycles is registered for every movement

speed, in order to reach, in further stages of analysis, reliable motor schemes of the competitors with the stabilized, average race walking speed. As a result of this registration we obtain the spatial image of markers position. (fig.4.)

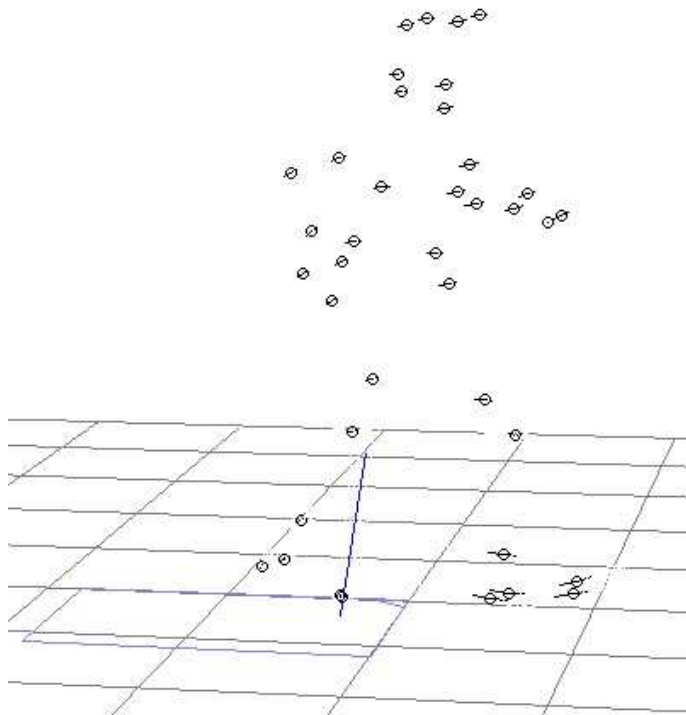


Fig.4. Three-dimensional image of markers position registered during the race walking (source: own research)

During the next stage of analysis we first make the markers' identification (fig.5a.), then we shape the movement with mathematical algorithm containing specific "structure of the body map", which as a result, after taking into consideration antropometric parameters of competitor's physique we obtain the three-dimensional image of competitor's skeleton

with the set of muscles. (fig.5b.) Depending on computational model used, the analysis provides wide spectrum of kinematic and kinetic parameters' values, which will be discussed below.

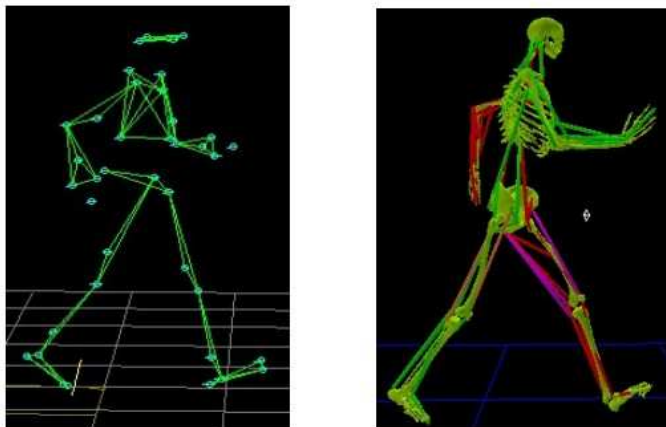


Fig.5. The markers position after identification (a) together with their mutual links in space (b) (source: own research)

The multimedia file, created in "Polygon" application, is used in order to present the obtained information about race walking evaluation. It allows to observe from any perspective of competitor's body movement in three-dimensional space and to follow simultaneously, in the real time, the values of analysed kinematic and kinetic variables characterizing race walking (fig.6.)



Fig.6. The race walker's movement sequence – the view from different perspective (source: own research)

The analysis of kinematic variables

Spatio-temporal parameters

What is important from race walking technique effectiveness point of view is spatio-temporal parameters optimisation, such as steps frequency, time of single and double support, cycle length and duration etc. in the context of their influence on the value of the developed race walking speed and COM oscillation range (fig.7.) The individual technique scheme of movement is to a large degree determined by competitor's somatic physique and spatio-temporal parameters resultant values. The competitors' individual movement schemes determine various technical solutions, which are the effect of movement optimization in relation to somatic physique (Ruchlewicz and co. 2007). Standardized values of these parameters allow to optimize movement technique from the point of exact length and frequency determination and the step frequency, also to good effect, allow to predict the values fluctuation of these variables in the ascending speed function of competitors' walk. (Chwała 2009).

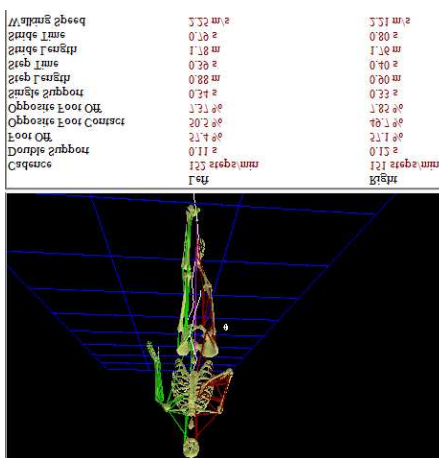


Fig.7. Spatio-temporal race walking parameters (source: own research)

Movement trajectories of osseous points and joints axis

The multimedia report gives the opportunity of spatial movement track observation of selected joints axis and osseous points in repeated cyclical movements during race walking. Fig. 8 presents the exemplary, spatial trajectories (movement tracks) of biomechanical tibial ankle joints axis, knee joints, hip joints and anterior superior iliac spine.

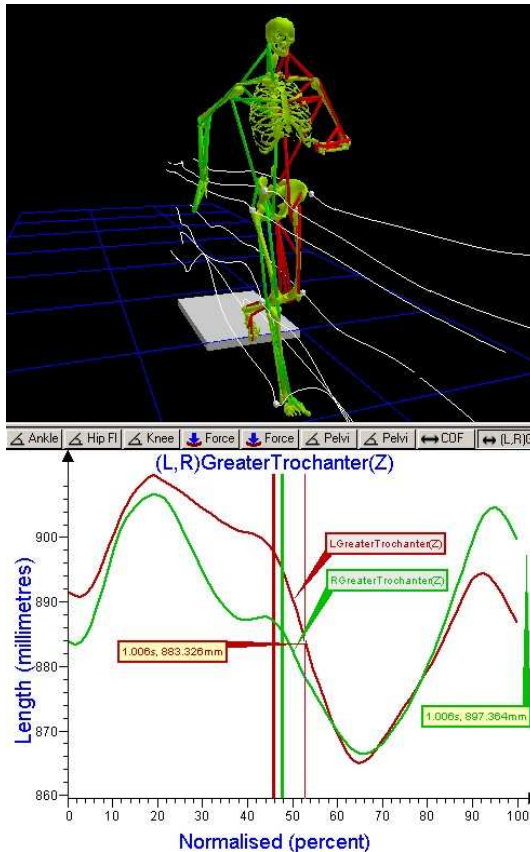


Fig.8. The spatial movement tracks (trajectories) of joints axis and osseous points. The vertical movement track of pelvis joint axis points are shown at the diagram (source: own research)

The movement trajectories analysis allows to evaluate asymmetry degree and movement range of chosen joints and osseous points on both sides of longitudinal axis of the body. They can be analysed in all three movement areas in any configuration sets. It gives the coach particular information about the errors in movement technique resulting from big movement asymmetry or mutual body segments position during competitor's movement and allows to precisely determine their range. The diagrams of all variables can be laid on each other and it is possible to observe their values in standardized time points of race walking cycle.

Changes of angles, speeds and angular accelerations in joints

Another significant kinematic variables are intersegmentary angle values and change of spatial segments position, in fact their constant fluctuation in particular phases of competitor's walk. Software allows to observe momentary and average spatial values of angular changes in all main lower and upper limb joints in normalized race walking cycle. These angles are included between neighbouring body segments, e.g. foot, gaskin and thigh, etc. (fig.9). Other category would be the angle position changes of all segments in measuring space against moving and changing constantly its orientation in space coordinate system with competitor's moving body. It gives the coach the possibility to observe the movement of e.g. pelvis, chest or head which angular changes are included in small few gradual scopes.

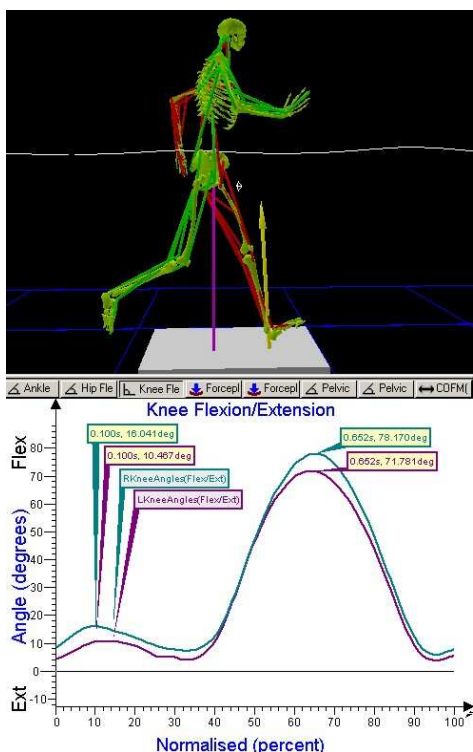


Fig.9. Temporary values of angular changes in knee joints of the race walker in normalized race walking cycle. (source: own research)

Because the angular change in joint in time function is resultant effect of acting on the body of all constituent forces, that is why knowing them is very important from competitor's movement technique evaluation point of view. More precise information is delivered by simultaneous analysis of angular changes in joint values together with speed and movement angular acceleration in joint (fig.10). The coach receives information not only about scope of angle change in particular race walking phases but also about dynamics of these changes.

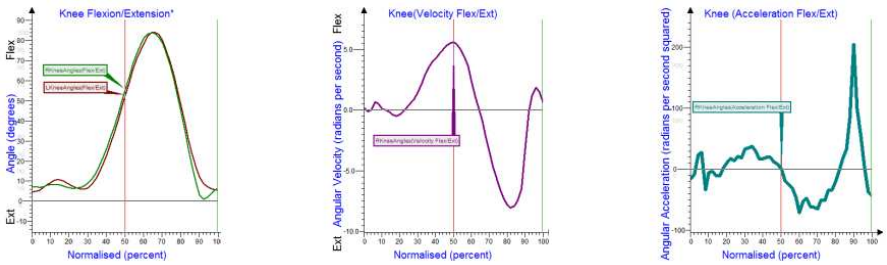


Fig.10. The angular change, angular speed and angular acceleration in knee joint in the same phases of normalized race walking cycle. (source: own research)

Muscle work evaluation

Muscle work evaluation is based on two important diagnostic variables: spatial change of mutual position of initial and final muscle insertions which reflects change of their length and muscle functional biopotentials values measured with global EMG. The measurement of bioelectric activity done with superficial electrodes shows phases and degree of muscle stimulation, expressed with relative MVC coefficient, and delay (latency) engaging the muscles to work in agonistic, synergistic and antagonistic chains.

Observing on the diagrams belly of the muscle length changes in context of their activity phases it is possible to assess the character of their work (concentric, eccentric), the symmetry of work, the scope of length changes and the order of their activation in biokinematic chains. Other important source of information is to compare on the same diagram the work of muscle antagonistic sets, especially two-articular muscles, allowing to formulate important conclusions regarding movement technique. (fig.11.)

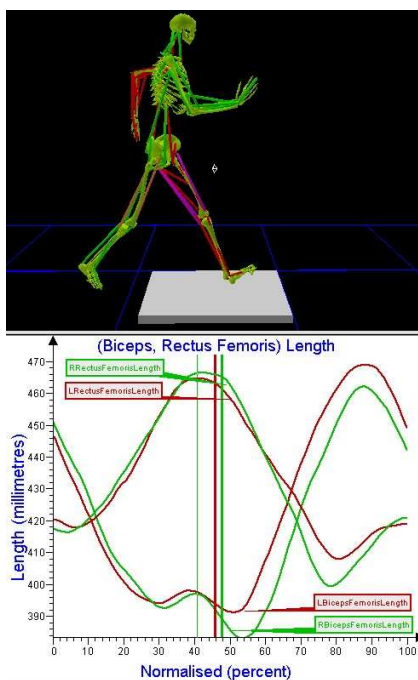


Fig.11. Comparison of rectus muscle and biceps femoris length changes in normalized race walking cycle (source: own research)

The evaluation of COM position changes

How it has already been mentioned above, the analysis of COM position changes has significant meaning in race walking's technique evaluation. On the one hand it allows to estimate the horizontal and vertical COM oscillation values, on the other hand it provides the information about race walker's movement repeatability in the next race walking cycles (fig.12.) The COM oscillation values decide indirectly about race walker's energetic consumption and serve as initial variable to assess the values of movement potential energy (EP) changes in each and every race walking cycle. After computing next derivatives COM displacement with respect to time, we obtain the components of speed and body's centre of gravity accelerations. On the other hand, COM speed constitutes the initial parameter for evaluation of developed race walking kinetic energy (E_k)

value. The familiarity with both types of energies is essential to assess values indicators of mutual energy processing and total biomechanical cost of race walking.

Knowing both types of energy is essential to assess the indicators' values of mutual energy processing and total biomechanical cost of race walking. Such an evaluation allows to search the competitor's optimal technique based on minimising energy expenditure, that is searching for compromise between length and frequency of step.

The knowledge of COM movement tracks projection position at the support surface provides important information about question of competitor's race walking stability.

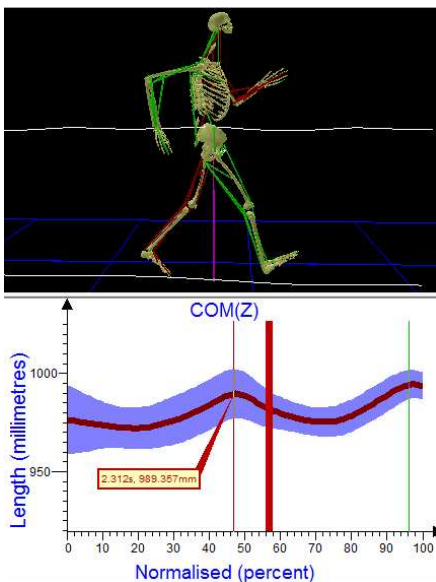


Fig.12. The COM vertical constituent position changes in normalized race walking cycle (source: own research)

The ground's reaction force analysis

Three dimensional systems of movement analysis co-operate with peripheral devices, such as dynamometric platforms measuring ground's reaction force components in the phase of foot's pressure on the ground.

The knowledge of vertical constituent value, front-back and transverse reaction force permits consequently to assess reaction force values in competitor's joints, developed forces moments and force generated in joints (Hoga and co. 2006). The analysis of shape and constituent value of ground's reaction force and reaction resultant force allows to assess effectiveness of dissolving movement system work in amortization and rebound phase which to a significant measure determines correct technique of movement. (fig.13). From own observation this evaluation is some sort of compromise between developed reaction force values and movement economics results from (Chwała and co. 2009).

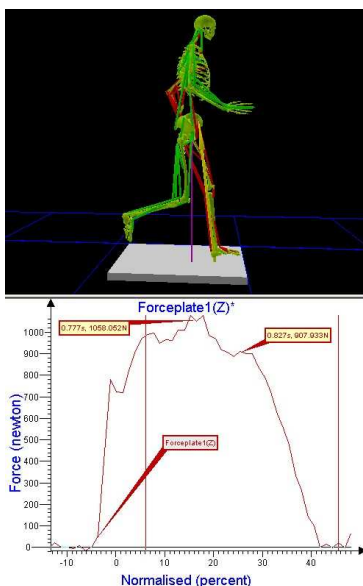


Fig.13. The reaction force at the platform and its vertical constituent values in normalized race walking cycle (source: own research)

Complex evaluation of competitor's motor condition

Complex evaluation of competitor's training condition includes the use of methodology, which is used by biomechanics and physiologists (Yoshida 1989). It allows both to assess the energy expenditure during the test of selecting corrective insoles for the competitor (Klimek and Chwała 2007), and to determine the influence of physiological and biomechanical

parameter values on the total energetic cost of race walking. The expiratory gas analysis made by modern portable ergospirometers together with kinematic and kinetic analysis of movement gives invaluable benefits in the evaluation of fatigue influence on the movement technique and optimal choice of physiological and biomechanical parameters of movement (starting speed, oxygen consumption level, length and frequency of steps). Thanks to having the information both about physiological and biomechanical cost at the same time it is possible to attempt the assessment of competitor's movement system efficiency, which reflects all elemental constituents of predisposition, technique and competitor's preparation to physical effort.



Fig.14. The experiment course of joining the measurement of physiological and biomechanical parameters (source: own research)

Conclusions

The application of more exact technical devices for the movement technique analysis in the training process is currently a necessity to keep

high level of sports results and to enter into competition on the highest world level. A competitor presenting high sport level, to improve it, has to reach for more precise diagnostic methods, which will provide him/her information serving a periodical sport technique control. They also give the rational benefits on the stage of teaching and technique improvement.

One of the possibilities that the three-dimensional analysis of movement technique gives, is using it not only for biomechanical description but also utilizing its results to its optimisation through introducing corrections in training process.

Presented in other works analysis of body segments movements and trajectories of centre of gravity shows (in spite of the highest sport level) the presence of asymmetry in race walking technique, which can directly influence race walking energy cost and indirectly affect the sport result. Unfavourable phenomenons on the level of average values in one race walking cycle are added on the starting distance.

The observed results of three-dimensional movement analysis constitute the base for improving the sport results through consistent elimination of technical errors in sports training.

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THE PROBLEM OF OBJECTIVITY IN JUDGING

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Key words: objectivity, judging, race walking, rules

Problem

The problem of objectivity in judging of race walking competitions has its roots in the judging technique of the moving of walkers. It is absolutely exceptional in the family of athletics: in other disciplines judges are obliged to control moving in delineated space (between the lines on the track, in circles for discus and hammer throw etc.). A kind of control of technique is required for example in shot put and triple jump, but in any case not controlled by eight judges all the time like it is in race walking. It seems to be so strange that there are some old fashioned beliefs that race walking does not belong to the athletics. These arguments are not familiar with the long-lasting history of race walking in the Olympics Games, of course with all the failures caused by the temporary exclusion of race walking from the OG program during several periods. The race walking is the firm part of athletics; IAAF Competitions Rules in a part Definitions named Track and Field, Road Running, Race Walking, Cross-Country Running and Mountain Running building athletics.

The aim of the study and methodology

Our aim is to show the limits of the objectivity in judging of race walking and possible ways how to increase the objectivity in judging. There are a lot of public discussions going on the topics. Looking at the problem of objectivity from the systematic point of view we can distinguish among different kinds of topics how to improve the objectivity of judging: these are rules, judges, and technical equipment. It means the definition of race walking, human ability of objective judging and technical equipment for the judging organization. We try to address only selected problems which are not visible at first sight during race walking competition. We also try to bring some proposals, new way of thinking how to improve objectivity of judging. We try to analyze the Rule 230.1, judging and technical equipment from the point of view if there are some possibilities to improve objectivity of judging.

OUTCOMES - RULE 230.1. - RACE WALKING AND Looking on the Table 1, we can see the position of race walking in the athletics family. No wonder there is great pressure on objectivity of judges. With so complicated rules and procedures how to judge, race walking lies in the end of the “table of objectivity”.

Table 1 “Table of objectivity”. Athletics family according to the control of technique of moving by judges

Parts of Athletics	Control of technique of moving	Other control	Rules	Keeping objectivity in judging
Mountain Running	No	Easy	Easy	Easy
Cross-Country Running	No	Easy	Easy	Easy
Road Running	No	Easy	Relatively easy	Easy
Track	No	Complicated, with technical equipment	Complicated	Relatively easy
Field	Yes, to some extend	Relatively easy	Very complicated	Relatively easy
Race Walking	Yes absolutely	Relatively easy	Very Complicated	Complicated

There have been many discussions what is right walking in comparison to running since the beginning of our discipline. The definition what the walking is was created not till 1928, but in 1908 walkers had already participated in the London Olympics Games. The objectivity was put into the hands and moral qualities of judges. In 1880 the Amateur Athletic Association in England (AAA) published the first Rules for Competition including race walking: cautions and disqualifications to be left to the discretion of the judges. The decision of the judges in each competition to be final. (Rule 14 and 15). You can see, the correct walking definition as

well as the behavior of the judges was left to their own interpretations. In 2010 we have definition of race walking, as well as exact procedure about the judging. Anyway, as regards objectivity in judging, explicitly formulated in the IAAF Rule 230, we are near to the AAA Rule 14 and 15.

From the beginning it seems to be clear that walking means “fair heel and toe” or “heel and toe on line” and everybody is able to see it and judge it. The first definition of race walking is from 1928 - walking is progression by steps so taken that unbroken contact with the ground is maintained – formulates finally the basic rule no 1 for the race walking – contact with the ground.

Rule no 1 “contact” still exist in contemporary IAAF Rule 230.1 definition of race walking (2010 – 2011). “Race walking is a progression of steps so taken that the walker makes contact with the ground, so that no visible (to the human eye) loss of contact occurs.

With the progression of speed the next characteristic of walking came into its discovering. The straightened leg as a rule no 2 occurred in 1956. In 1972 came the other explanation - the leg must be straightened (not bent in the knee) “the supporting leg must be straight in the vertical upright position”. Since 1956 with the specification in 1972, the rule 1 and the rule 2 for walking have been the basic characteristics describing what is right walking and what is not walking (in fact what is running).

Mexican style of walkers fascinated the world from the 1968 for several decades. Development of speed requires new specification of the rule 2 in 1996: The advancing leg shall be straightened (i.e. not bent at the knee) from the first moment of the first contact with the ground until the vertical upright position”. It is the second sentence in definition of race walking in contemporary IAAF Rule 230.1. We are witness of how rules follow advancing technique of athletes, and not how the top athletes follow the advanced rules. I consider this tradition very important: it gives us traditional continuation with the previous history of race walking but is open for the new specifications based on the performance of top walkers.

From this point of view, increasing objectivity does not require the change of the Rule 230.1. Definition. There is the other paradox: ultra distances and

many masters competition used only the Rule 1. It is good if we call it walking. But we can not call this progression by steps “heel and toe on line” race walking. Race walking means to adopt the Rule 2, not bent knee, too. This is the difference between right walking and right race walking. In England it is called the Rule B (contact with bent knee), despite the fact that IAAF Rule 230 concerns Race walking does not know any Rule B (or A etc.) The definition of race walking is only the one mentioned above, operating with the contact with the ground and straightened (i.e. not bent at the knee) leg.

Even from the biomechanics point of view, the straightened (i.e. not bent at the knee) leg makes the main difference between running and walking: body gravity axis are copying two peaks during the step according the definition of race walking. Running means to make one peak for body gravity axes. (Sušanka, 1975, 1978). We can see the difference between walking and race walking naturally not only on the video from biomechanics laboratories. It is difference between normal walking and walking with high speed. High speed requires naturally other technique of steps and body moving. The advanced (professional) technique is called race walking. In fact every definition of walking and race walking is in relationships to running. Walking is considered to be the opposite of running.

OUTCOMES - JUDGES AND JUDGING IN RACE WALKING COMPETITIONS:

As mentioned above, there is not explicitly written what objectivity in judging in the IAAF Rule 230 means. But we can find many feedbacks developed through practice whose purpose is to eliminate subjectivity in judging.

Repeating number of 3 independent judges, 3 red cards from them for disqualification of one walkers, judges from different countries in international competitions – these are explicit rules for the procedure. There also exist explicit rules how to judge: all judges shall act in an individual capacity (as individuals) and their judgment shall be based on observation made by human eye.(IAAF 230.2b) There exist booklets how to judge, how to organize positions of judges, and the Code of ethics of race walking judges.

Anyway, the problem of objectivity in judging of race walking exists in spite of all these rules and booklets. To analyze this part, we need to look at:

- a) Physiology of human eye
- b) Process of judging
- c) Social context
- d) Moral values of judges
- c) Limits of consistency in judging

ad a) Physiology of human eye: "...no visible (to the human eye) loss of contact occurs" is written in the Rule 1 of race walking. This inability of human eyes is often the source of many conflicts. Normally, the human eye is not able to recognize the loss of contact up to 50 milliseconds (it means that it is not able to split the movement into shorter sections). A high frequency camera in laboratory shows that the walkers on the top level have no contact with the ground for 30 milliseconds. Judges as well as spectators evaluate it like a contact and they are right according to the Rule 230.1. Individually, if the loss of contact is higher than 60 milliseconds we are able to recognize the loss of contact with the ground looking from the site on passing walker.

The problem is clearly visible in the random photos showing just the loss of contact of walkers published in media. It is the same problem like with a playing by hand in football which is not visible for judge, but visible for camera. Using slow video record shows the same problem. There is clearly visible every step and every loss of contact, but the judge cannot slow down moving walkers. To sum it up, in case of keeping the IAAF Rule 230, the rule 1 in definition of race walking, we cannot be absolutely objective, because of physiological limits of human eye.

Ad b) Process of judging: judging in fact means to evaluate something according to the patterns what is correct and what is not correct. The construction of the right patterns is a question of previous experience and repeating of cases of good and bad practices. There is an open door for the education of judges using examples, pictures, videos etc.

Ad c) Social context: social context can change the patterns what is correct. Feeling great responsibility during the Olympic Games, finishing walkers, media, spectators and last 10 - 5 meters fails to comply with the Rule 230.1. It is not theory, but life with all complicated consequences. Was it obvious? Did everybody mention it? What is worse for race walking? What is worse for me as the Chief Judge? Patterns of right technique are not

static parameters, but under the social and cultural context are more important than we think.

Ad c) Moral values of judges: independency on athletes, coaches, organizers, other judges and IAAF representative bodies is required but not so easy to keep in practical judging. It does not mean that objectivity lies on the mechanic application of the Rule 230 at all costs. On the contrary, judges should be an intelligent part of the competition. If their role should be only to keep the rules without any feedback to athletes and conditions, they can be replaced by computers completely. It concerns all athletics events.

Ad c) Limits of consistency in judging: there are at least two kinds of consistency – qualitative and quantitative. As regards qualitative consistency, the team of race walking judges must have the same approach to athletes and competitions. Calculating qualitative consistency is possible only indirectly, but it is clearly visible on behavior of judges to walkers and spectators. They must be not enemies, but officials who provide fair play competitions.

As regards quantitative consistency, absolute objectivity requires to be 100% consistent in terms of every judge sent red card to the same athletes for his/her disqualification. This is possible in theory, but not in practice. If the team of judges reach more than 60% of consistency in disqualification of walkers it is very good scoring, more than 70% is excellent. Despite of the used method of counting consistency, 100% of consistency for every method means there is no single red card, no double red cards per walker, only disqualifications or nothing.

OUTCOMES - TECHNICAL TOOLS IN JUDGING:

Briefly, there is no technical tool for judging of race walking explicitly mentioned in the IUAFF Rule 230. On the contrary, there is a remark about the loss of contact visible by human eye.

Looking at the main obstacles with objectivity in judging of race walking we can see the limits of judges (general human limits) in their ability to reach high consistency near to 100%. There are barriers mentioned above, some of them objective - physiology of human eye, some of them

subjective - moral values, some of them giving differences in social and cultural context. We cannot eliminate all of them. But we can reduce some of them.

The big misunderstanding is still the rule 1 in definition of race walking – the loss of contact with the ground. Is it visible or not? If it is visible for camera and not for judges what about objectivity of judging?

Vision of implementation of technical tools:

Our proposal is easy: to use technical tools. Many sports use advanced technology to help them in judging. Tennis, ice hockey are good examples. There is no reason to be conservative and lose objectivity and race walking from the OG. Let's "clever shoes" go into our sport. There is no space for discussion about technical details and technical solution. It will be found very fast if there is common demand and we will be open for modern tools with the old tradition of race walking. Economical laws sometimes work...

How to control contact with the ground? Is it possible? It is!

We need clever equipment, something like chip / transponder system, with control record similar to the lap counting. A lot of electrical tools do exist now and are used in marathons and our race walking competitions. They are arguments against using the "clever shoes" that it is impossible to make a contact in every steps and everybody will be DQ. These arguments are out of fashion, out of today technical development. It is possible to develop a program with a tolerance to loss of contact in milliseconds like it is in real competition judging by human eyes. There should be empirical based percentage of total time allows loss of contacts and it should be easy to record the program into the clever shoes with the transferable detector - chip. Our cheap sport needs the interest of hi-tech companies. There is potential how to open our sport for the higher participation of fit-walkers using these "clever shoes". Fit-walkers should be the first step for race walkers. Fit-walkers can participate in their own categories together with race walking competitions – the loss of contact judging will be provided automatically by "clever shoes" and recorded on the Posting board without any influence of the judge. We can image "clever shoes" also for training of the professionals like a perfect tool how to improve and control the correct technique of race walking.

Consequences: What will the role of judges be?

Of course, the “clever shoes” do control only contacts. Race walking judges still control our rule 2 according to the definition of race walking in the IAAF Rule 230.1. It means that leg should be straightened (i.e. not bent at the knee), the judges make a cautions, the Chief Judge disqualifications, etc. There is no problem to make a cautions for the loss of contact with the ground to have an information about the percentage of total loss of contact coming from the chip, or other feedback system.

Consequences to the IAAAF Rule 230.1

Our rule 1 should not be changed – only the following amendment should be put into formulation: “Race walking is a progression of steps so taken that the walker makes contact with the ground, so that no visible (to the human eye OR BY HELP TO THE HUMAN EYE BY AUTHORIZED TECHNOLOGY) loss of contact occurs.”

To be open for the advanced technologies, we can go forward to modern social attitudes to be a part of story, to be active, to offer something new for the public area. Using the modern technology is one of several possibilities how to improve objectivity, fairness and transparency in the judging system of race walking.

Conclusion

Judges and judging process cannot be absolutely objective, there are limits in physiology in human eye, limits in social skills, moral values etc. On the other hand, there is an open door for improving the objectivity by partial professionalism of the international race walking judges. There is a paradox: athletes and coaches have become more and more professional, judges are still amateurs with their own jobs plus their hobbies to judge international competitions. It is strange in 21st century, is not it? Many sports use advanced technology to help them in judging. Tennis, ice hockey are good examples. Let’s “clever shoes” go into our sport. There are arguments against using the “clever shoes”. It is impossible to make a contact in every steps and everybody will be DQ. These arguments are out of fashion, out of today’s technical development. It is possible to develop a program with a tolerance to the loss of contact in milliseconds like it is in real competition judging by human eyes. There should be empirical based percentage of total time allowing the loss of contacts and it should be easy to record the program into the clever shoes with the transferable detector -

chip. Using modern technology is one of several possibilities how to improve objectivity, fairness and transparency in the judging system of race walking.

Summary

The study analyzed the definition of race walking, human ability of objective judging and technical equipment for the judging organization from the point of view how to increase objectivity of judging in race walking. Results show increasing objectivity does not require the change of the Rule 230.1. (Definition of Race Walking). Looking at the judges and judging there are strict limits in term of: a) Physiology of human eye b) Process of judging c) Social context d) Moral values of judges c) Limits of consistency in judging. To reduce some of the limits we proposed using advanced technology in race walking, replacing the loss of contact judging by “clever shoes” with the program with a milliseconds tolerance of loss of contact, with some empirical based percentage of the total loss of contacts. Using the modern technology is one of several possibilities how to improve objectivity, fairness and transparency in the judging system of race walking.

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THE PROBLEM OF CONSISTENCY IN JUDGING OF RACE WALKING

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Abstract

The study provides a contemporary overview of the current problem of consistency in judging of race walking. There are two kinds of consistency important for the race walking judges: qualitative and quantitative. The qualitative consistency in race walking can be defined like a consistency of opinion, acting and communication of the judge. Six categories fit to the definition: Punctuality, Concentration, Behavior, Independency, Team communication, Athletes communication. The formalization of these categories is relatively easy; the question is who could evaluate it? The qualitative consistency is based on two main approaches: linear and non-linear. The linear one is used like calculating average and simple linear consistency. The great disadvantage is the possibility to increase the individual consistency by “calculated red cards activity”, means more red cards. For our purpose - practical implementation of the model which avoids the disadvantage of the linear model and will be used for individual calculating of consistency – we need more developed model based on the empirical experience. We tested our non-linear model using six variables. Now our model is a part of our developed Judging Summary Sheet and ready for the right use just immediately after filling the Judging Summary Sheet.

Key words: qualitative consistency, quantitative consistency, linear model, non-linear model, judging, race walking

Problem

The term “consistency” has a lot of meanings: compliance, accordance, cohesion, integrity, unity, harmony etc. There are several definitions of consistency on the website: harmonious uniformity or agreement among things or parts; the property of holding together and retaining its shape; logical coherence and accordance with the facts. The problem of consistency concerns marketing, psychology, general statistics (Teknomo, 2006). Of course, the problem of consistency in fact affects every judging in

sport, million links could be found on the internet, from open discussion about football judging to serious analyses. As regards race walking, consistency is used in two ways: in qualitative way like integrity, cohesion, unity of performances and behavior of judges, and in quantitative way like mathematical based accordance of red cards contributed to disqualification of walkers. Both topics are at the beginning, the qualitative is more developed in the Code of ethics of race walking judges, based on the Code of Ethics of the IAAF, as adopted by the IAAF Council in November 2003. The quantitative approach to consistency is undeveloped, there are a few serious studies discussed below (Magio, 2008, Daniel, 2009).

The problem of consistency in judging of race walking events is in fact the problem of quality of race walking. It is the problem of in-consistency in judging and behavior of race walking judges behind the discussion about excluding race walking from the program of the Olympic Games. Discussion about subjectivity of judging, about unfair judging, all of these are results of in-consistency. The athletes and coaches have become professional, but judges are still amateurs, despite the strong evaluation of judges every four years provided by the IAAF. In this context and on this level we need theoretical as well as practical concept of consistency in judging of race walking.

Goal

The goal of this article is to bring general overview of qualitative and quantitative consistency in race walking judging as well as the examples of practical use. Can we increase the consistency in race walking judging? We want to stress that the qualitative as well as the quantitative consistency are only the tools for improving the quality and fair-play judging. It is influenced by many factors which cannot be formalized, like experience, motivation, cultural and social background of judges. All of these factors create the judging.

Qualitative consistency – methodology

The IAAF Competition Rules, in our case of race walking, the Rule 230, do not help us too much. There are five lines about definition of race walking; the rest of page is dedicated to the procedure of how to judge. The consistency is not mentioned in the Rule 230, but in the paragraph 6a and 6b – Disqualification - is based on consistency of three judges, of course.

Referring to the Code of ethics of race walking judges and to the experience with the international competitions held under the Rule 1.1a-h) we can provide easy definition of consistency: *Qualitative consistency in race walking can be defined like a consistency of opinion, acting and communication of judge.* Opinion, acting and communication are three pillars of qualitative consistency. We can divide them into following categories:

Opinion:

Punctuality:

Means not only to be in time in his/her designated section, but to fill correctly his/her sheet of race walking judge with the correct bib (start number) time of caution and disqualification (DQ). It is very important for the judging Summary Sheet to get the correct information. The jury of appeal usually used race walking sheet like the first evidence in case of protest.

Concentration on the competition

Means not only to concentrate on the leading group, but to keep concentration to the end of all races. The technique of race walking usually change during the race, concentration means to be careful on passing athletes all the time. It is not so easy to keep concentration for 5 hours in the 50 km race, several shorter races included. It is clear that good concentration requires good physical condition as well as familiarity, experience with these kinds of races.

Acting:

Correct behavior during races

Means race walking judges are not enemies of walkers! Yes, he/she has the power to DQ any athletes failing to comply with the definition of race walking, but the role of judge is only to provide a fair-play race, nothing more, and nothing less. It is not allowed to have any contact with spectators or team officials or other athletes, particularly those who may be identified as members of any Member Federation; to use a mobile phone, radio transmitter or similar device at on the course to inform coaches and other people about the progress, positions of athletes etc. Race walking judge is a part of competition, not a part of national team. It is not allowed to have any active interest on the Posting Board (Board with the red cards, called also DQ board). The correct behavior means also to dress an appropriate uniform.

Independency

Means to keep his/her given section, avoid any discussion with the other judges, spectators, athletes and coaches. Independency is based on her/his own judging, it can be under supervising of the Chief Judge only during the race, but without any direct changes in his/her decision. Independency also means to be independent on team or athletes position. On the other hand, communication with the Chief Judge about every problem of competitions is necessary, if failing to comply with any IAAF Competition Rules. Independency means: I am responsible for my judging, it is my own responsibility and I can publish it and defend it if necessary.

Communication:

Social skill in team communication

Means not only language ability. It is necessary for communication in/ during international competitions, but social skill has broader meanings: to solve the problem, to avoid conflicts, to be open for improvisation. During the race walking meetings before and after the competitions (pre and post – race meetings) is good occasion to use your own social skill to help to build the team..

Social skills in athlete's communication

There is not allowed direct communication with passing athletes about their progress, positions etc. On the other hand, every caution (yellow paddle) showing to the athletes is a part of communication according to the Rule 230. 4. It must be clear that a walker notes the yellow paddle and his/her bib (start number). If necessary do not hesitate to point by finger to the athletes „you are“, because not everybody understands how to read the bib, not mentioned the fact that not all athletes understand English or your mother language. If there is a serious need to help to the athletes - in case of injury, medical cases etc, do not hesitate to do it. After the competition there should be a feedback with athletes and coaches, if possible and required from their site. We need to break barriers between athletes, coaches on the one hand and judges on the other.

The question is who will evaluate race walking judges? The first person in direct contact with all judges is the Chief Judge. The other is technical delegate. These two people are responsible for the competition, but only if they have the confidence of judging team, there could be some evaluation. In great competitions held under the Rule 1.1. a) there could be an appointed person to provide the qualitative evaluation.

The example how to evaluate qualitative criteria follows

Table 1 Formalization of qualitative criteria

No of race walking judge:

Opinion	Acting	Communication	Scoring
Punctuality 0-5	Behavior 0 – 10	Team 0 - 10	
Concentration 0-5	Independency0- 10	Athletes 0 - 10	

Name of evaluator:

Date:

Competition:

Comments: The maximum points which can be obtained are 50 in this case. As you can see, there is stressed correct behavior, responsibility of every judge for his/her own decision and ability of communication – with the athletes during and after the race. The question is how exactly it should be controlled by evaluators, but this problem is small in comparison with the advantage to take the first step in terms of evaluation of qualitative criteria and improving the consistency in race walking international competitions.

Recommendation:

There are still barriers between athletes and coaches on the one hand and judges on the other. In order to break the barriers the Summary of Chief Judge could be a part of the results. Names of judges could be replaced by numbers. It is only convention hidden behind the paper work. On the post-race meeting, the race walking judges can vote for the publishing of the Judging Summary Sheet with the full names. We have experienced this method several years before: after the first skepticism it has become a regular part of Podebrady web site meeting and Lugano meeting. We need feedback between athletes and judges; the Judging Summary Sheet is a good example of how to do it in an easy way without any changes in the Rule 230.

Quantitative consistency – methodology

In general qualitative consistency the rate of red cards is variable. The problem occurs just at the beginning: there could be several explanations what the rate of red cards means.

1. red cards (RC) sent by one judge – in this case we can speak about individual consistency
2. RC sent by all judges – team consistency

There are usually three variables:

- a) the number of red cards (RC) sent by individual judge on DQ walkers,
- b) total number of RC sent by individual judge,
- c) total number of DQ athletes

According to the construction of using methods for calculating consistency we can speak about linear and non-linear consistency in race walking. We are trying to introduce the main approaches, from the easy ones to non-linear model which can be put into the Judging Summary Sheet like a program counting immediately individual consistency of every judge just after the completing the Judging Summary Sheet by recorder.

Average

This is very easy method, giving overview about the arithmetic average number of RC of every judge.

- Advantage: easy for application, everybody is able to find average of every judge in the Judging Summary Sheet, useful for the first look at the results of judging.
- Disadvantage: there is nothing about real consistency. I can have the same average like the team average is, for example 6 RC, but non of my RC contributed to DQ of a particular athlete, so there is in fact no consistency with the other judges.

Simple linear consistency

This method uses two formulas:

Formula 1. The number of red cards (No of RC) sent by individual judge on DQ walkers/total number of DQ athletes. (Judge can reach values from 0 – 1 . 100 = 0% - 100%)

Formula 2. The number of red cards (No of RC) sent by individual judge on DQ walkers/ total number of RC sent by individual judge. (Judge can reach values from 0 – 1 . 100 = 0% - 100%)

- Advantage: relatively easy for calculating. Total no of DQ athletes is known just after the race, easy to calculate it in per cent.
- Disadvantage: this linear consistency means more RC sending by individual judge to improve his/her probability of consistency.

Testing formula 1.

There is total number of 4 DQ walkers in the race. I sent 1 RC on DQ walkers, my rate is $1:4 = 0,25 \cdot 100 = 25\%$ of consistency. The other judge sent also 1 RC on DQ walkers, has the same rate, by his/her total number of

sent RC was 10. You can feel the big difference between 1 and 10 sent RC and the same scoring. But total number of RC sent by individual judge is missing variable in this formula. In theory, if I send RC to every walker, I can reach the 100% of consistency in this linear model. From this point of view it is not only theoretical problem. It is ethical problem, too. In the interesting article (Maggio, 2008), authors tried to calculate team consistency on the great pool of collecting data from the Judging Summary Sheets from many Italian competitions. He used just formula 1.: "the number of Red Cards sent by the individual judges who contributed to the disqualification of a particular athlete/ the total number of athletes disqualified in the race". From the ethical point of view the following note is important: „It is easy to see that the higher the number of Red Cards sent by the single judge, the greater the possibility that the value of will be high. We can point out here that the primary task of a judge is to "judge," not to raise his/her index evaluation“. (Maggio, 2008, p. 44).

To avoid this trap of linear consistency, some authors used formula 2. „This index (also expressed as a number from 0 to 100) has the specific purpose of mitigating the effect of a large number of Red Cards issued by a single judge compared to his/her colleagues“ Maggio, 2008, p. 44.

Testing formula 2.

In our example, I sent 1 RC on DQ walkers and my total number of sent RC is also 1. $1:1 \cdot 100 = 100\%$ of consistency. The same race, the other judge who sent 10 RC and 1 of them was on DQ walkers (contribute to DQ of a particular walker). $1:10 \cdot 100 = 10\%$ of consistency. Again you can see and feel the big difference between 1 and 10 sending RC, despite the fact that number of DQ walkers was the same (4 like in our previous example). In this case less activity means great advantage, and in theory no RC sent by any judge can be 100% of consistency if there are no DQ walkers. What is missing is the total number of DQ walkers in this formula 2.

That is the reason why some authors suggest combination. Maggio (2008) call it Technical Assessment Index, (TAI, can reach the values 0% - 200% because of combination of formula 1 and 2). Daniel (2009) put combination on the table of additional analyses. "I've created the following analysis: red cards that were on a disqualified walker to total disqualified walkers (0.0% to 100%) and red card on a disqualified walker to total red cards by judge (0.0% to 90.9%) ". The percentage are results coming form

the data of 9 international events held under the Rule 1.1 a, b and c), more important are the same formulas 1 and 2 mentioned above.

Daniel and Maggio (2009, 2008) used this formula 1 and 2 for the evaluation of team consistency. Then statistic is based on relatively great pool of collecting data from the Judging Summary Sheets from many Italian, US as well as international competitions. It is good tool for long-term retrospective evaluation of race walking judges' activities. Usually, we have no such data per every judge and no time to use this team evaluation just after the competition. This is the reason why we formulate non-linear model of consistency for practical implementation.

Non-linear model of consistency – methodology

Demands on the ideal model are following:

1. Individual evaluation: we need to know how much consistent in terms of quantitative consistency is every judge in the race,
2. Avoid the disadvantage of linear consistency as mentioned in formula 1 and 2 to save walkers against “calculated red cards activity” from judges who knows the increasing (decreasing) number of red cards means increasing probability of consistency.
3. Take into account the number of participating walkers and level of competition
4. Be able to calculate individual evaluation just with the result list
5. Program to be friendly used and integrated into the Judging Summary Sheet

We try to introduce a model able to reach all of demands above, if possible. Looking on the formula 1 and 2 there are missing variables: total number of RC sent by individual judge is missing variable in formula. 1 and total number of DQ walkers is missing in formula 2. It caused the problem with linear dependency in terms more RC means increasing probability of consistency, or on the contrary, less activity increase probability of consistency. Both extremes are not only theoretical, but also ethical questions how to protect participating athletes against “calculated red cards activity”.

In real competition we can get following variables:

- Total no of RC sent by individual judge

- No of RC sent by individual judge on DQ walkers – consistency with at least 2 and more other RC , we will call it *DQ consistency*
- No of RC sent by individual judge together with other one - 2 RC consistency, we will call it *double consistency*
- No of RC sent by individual judge with no one consistency - we will call it *single RC*
- Total no of DQ walkers
- No of participating walkers

The experience show that we need to avoid extremes on the both ends of activity and to take into account the level of the race and the number of participating walkers. It means to penalize “calculated red cards activity” in terms of increasing (or decreasing) number of RC sent. On the other hand, some toleration regarding position of judge and the number of passing walkers is needed, to be as much fair as possible to judges and athletes. About five years ago we tried to test our non-linear model on the great IAAF and EAA competitions, directly during the events or ex-post. There is one condition for the successful application of the model: to have the Judging Summary Sheet carefully filled, in electronic form if possible, using excel. Our model is derived from reality of race walking competitions, not from the statistical theory. Our non-linear model will be tested by extreme values in next paragraphs.

DQ consistency =

$$\left(\frac{RC_{dq} * 1}{DQ_t * \sqrt{RC_i}} \right) * 100$$

Where:

RC_{dq} = No of RC sent by individual judge on DQ walkers

DQ_t = Total No of DQ walkers

RC_i = No of RC sent by individual judge with no one consistency .

100 to get result in per cent points.

Part of formula $\frac{RC_{dq}}{DQ_t}$ can reach values 0 – 1.

Testing limits of the formula: $\frac{RC_{dq}}{DQ_t}$ can be 0 in real competitions, it means, judge has no consistency with any DQ walkers. In this case, result is $0 \rightarrow$ If $\frac{RC_{dq}}{DQ_t} = 0$ than result of consistency = 0.

No of DQ_t can be 0. It happens. In this case result of $\frac{RC_{dq}}{DQ_t}$ must reach value 1, because it represents a particular case of consistency. Nobody was DQ, so judge cannot reach other value RC_{dq} than 0. DQ_t is logically 0, too.

But 0 cannot be in nominator. For reaching $\frac{RC_{dq}}{DQ_t}$ value 1 are values of

RC_{dq} and DQ_t automatically changed to 1. \rightarrow If $DQ_t = 0$ than $\frac{RC_{dq}}{DQ_t} = 1$.

Explanation: Nobody was DQ, it means the first part of formula $\frac{RC_{dq}}{DQ_t}$ must be 1, because the judges get 100% of consistency in DQ. But

in the second part of formula $\frac{1}{\sqrt{RC_i}}$ can every judge decrease his/her consistency depending on number of RC_i .

$\sqrt{RC_i}$ is important variable, avoiding in fact calculating red cards activities and saving athletes from a lot of single red cards. On the other hand, you will see, amount of 1, 2 red cards sent by judge like a single cards, does not influence so much his/her scoring, because the course of function is non-linear, but parametric following our formula $1/\sqrt{RC_i}$.

There could be 0 in RC_i . It means judge is able to make consistency with all DQ walkers, without any single red card. It happens. In this case we calculate value 1 in the part of $\frac{1}{\sqrt{RC_i}}$ in our formula. \rightarrow If $RC_i = 0$ than

result of $\frac{1}{\sqrt{RC_i}} = 1$. (Again 0 cannot be in nominator, RC_i is changed to

value 1 in this case automatically.)

This model shows consistency behind the average and behind the linear formula with two variables and is very close to the empirical reality of judging in race walking competitions.

Table 2 The course of non-linear consistency, example

Notes: We have the same race. There were the total number of 4 DQ athletes.

No of RC contributing to DQ sent by individual judge	No of single RC sent by individual judge	$\left(\frac{RC_{dq} * 1}{DQ_i * \sqrt{RC_i}}\right) * 100$	* 100 (per cent points)	Scoring (in %)
1	0	$\left(\frac{1}{4} * \frac{1}{\sqrt{1}}\right) * 100$ (no single RC per this judge)	1:4 = 0,25 * 1:1 (see limits 0= 1) = 0,25 * 100 = 25	25
2	1	2/4 * 1/√1	2:4 = 0,5 * 1:1 = 0,50 * 100 = 50	50
3	1	3/4 * 1/√1		75
4	1	4/4 * 1/√1		100
4	2	4/4 * 1/√2	1 * 0,70 * 100	70
4	3	4/4 * 1/√3		58
4	4	4/4 * 1/√4		50
4	5	4/4 * 1/√5		45
4	10	4/4 * 1/√10		31
4	20	4/4 * 1/√20		22
3	5	¾ * 1/√5		33
2	6	2/4 * 1/√6		20
1	7	¼ * 1/√7		10
0	0			0
0	Total No of participating walkers – 4 DQ walkers in this case			0

Double consistency =

We need to know double consistency, too. It is the same formula now transformed to double consistency:

No of RC sent by individual judge contributing to other one RC/ Total No of double RC * 1/√ No of RC sent by individual judge with no one consistency * 100 to get result in per cent points.

We can write the formula in the following way

$$\left(\frac{RC_2}{RC_{2t}} * \frac{1}{\sqrt{RC_i}} \right) * 100$$

Where:

RC_2 = No of RC contributing to other one RC

RC_{2t} = Total No of double RC

RC_i = No of RC sent by individual judge with no one consistency.

100 to get result in per cent points.

$\frac{RC_2}{RC_{2t}}$ can rich values 0 – 1. For particular case $RC_{2t} = 0$, then the same condition like in the previous formula for DQ consistency. If $RC_{2t} = 0$, then RC_{2t} and RC_2 is changed to 1 for the counting.

Cautions:

There is no methodological barrier to evaluate cautions in the same way, but we need to take into consideration the purpose of cautions. The purpose of caution is to announce athletes there are in danger of failing to comply with the Rule 230.1. definition of race walking. Yellow paddle can help them improve the technique of walking, if they are able to do it. In this case it seems to be nonsense to put caution on the formula mentioned above, because we cannot compare two kinds of consistency, two tools using by race waking judge. The most important is to look at the Judging Summary Sheet to know if DQ walkers have been cautioned by judge without any DQ or double consistency. This is very important for the correct evaluation. If yes, walker was cautioned, the question is about the limit of tolerance, not about the inconsistency in terms this failing to comply with race walking definition which was not visible for the judge.

Statistics based on empirical studies shows the number of 50% of cautioned athletes recoded on the red card. We can consider this rate as a good average. But it depends on race and athletes very much, more about the problem in Maggio (2008).

What is good and what is pure consistency?

The non-linear model, which shows number of RC contributing to DQ sent by individual judge, is a leading variable. Of course, we need as much DQ consistency as possible; the worse thing for athletes and spectators is a great number of single red cards sent to nearly every participating athlete. Model shows that there are three parts, from 0%- 30% is pure DQ consistency, over 30% up to 50% is average, from 50% – 75% is a very good consistency, over 75% to 100% is the excellent DQ consistency. To calculate double consistency has its sense particularly if there is no DQ athlete. The scale is the same, because using the same formula and system. The comparison between DQ consistency and double consistency is clearly visible on the bar graph. There is no problem for the program to calculate also team consistency like the arithmetic or other average of the obtained data. For our purpose to get survey of individual consistency of every judge, we consider this part of graph as additional information.

Number of participating athletes and changing parameters of the presented model:

The great advantage of the presented model is its variability. Everyone has their own experiences with the different local and great international race walking competitions. In dependency on the level of competition and number of participating athletes in one race, we can modify parametric values in a part of our formula $1/\sqrt{\text{RC}}$ single. Briefly, more passing athletes usually mean more tolerance to single RC sent by individual judge. The table below indicate proposed tuning of the model. The example presented here are tuned on the EAA permit meeting in Podebrady, > 110 athletes participating in one race, 7 -8 race walking judges, 1 km lap, passing athletes are visible only one way, i. e. 20 times per race (10 times per junior race).

Table 3 Possibility of tuning the model

Level of the race	Approx. No of participants in one race	Model used	Parameters 1/ \sqrt{RC} single
National local	Up to 40	average	-
National championships	Up to 50	Simple linear formula 1 and 2 or non-linear in case of number near to 50 participants	-
EAA and IAAF permit	Over 50 – up to 120	Non-linear	0; 1 – 2 single RC = 1
Area championships	40 – 80	Non-linear	0; 1, 2 single RC = 1
World cup	60 – 150	Non-linear	0; 1, 2 -3 single RC = 1
OG	40 – 80	Non-linear	0; 1, 2 single RC = 1

Examples (with permission of the Chief Judge and the judges)

JUDGING SUMMARY SHEET (RACE WALKING) Podbrady Walking 2010

1 of 2		DATE		EVENT		CHIEF JUDGE'S NAME AND SIGNATURE																				
		10-4-2010		10km + 20 km Woman		Miroslav Laska																				
Number	Starts	RC		RC		RC		Chief Judge	Disqualification	CHECK OF	Comments	RE														
		A	B	C	D	E	F																			
95																										
103		35.02			34.47		34.25		34.25	35.51		14.25	15.01	3.00	2	2	3									
94					34.47		34.57			35.05					1	1	1									
93	14.96	35.03			34.52				34.59				34.50			3	1	1								
174	15.00		34.46		35.00				34.29	35.03		15.00		34.26		4	1	2								
153							34.30		35.00				34.30	35.24		0	2	2								
100										34.59			34.59	35.25		0	2	1								
152					35.12					35.15	35.25			35.20		0	2	3								
105		35.33	14.55	35.39	35.37				15.49			15.17		35.49	16.09	3.00	1	5	3							
157		35.24														0	0	1								
86											34.53	35.27				0	1	1								
155						35.22	35.28									1	0	1								
87					35.10					35.08	35.11	35.20	35.30			1	2	2								
83		35.25			34.52									34.25		1	1	1								
99			35.09													1	0	0								
CHECK PAGE	~	<	RC	~	<	RC	~	<	RC	~	<	RC	~	<	RC	DO	CH	DO	Page	~	<	RC				
	2	0	5	3	0	2	5	2	2	1	2	2	0	0	4	4	3	3	4	1	4	4	0	3	15	23
CHECK TOTAL	~	<	RC	~	<	RC	~	<	RC	~	<	RC	~	<	RC	DO	CH	DO	Total	~	<	RC				
	2	0	5	3	1	2	5	3	2	2	3	2	0	0	5	4	3	4	4	1	5	4	0	3	24	23

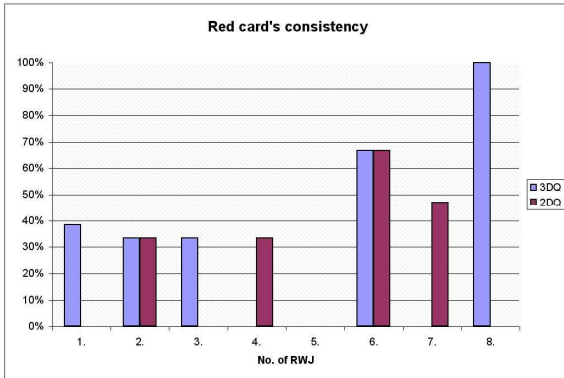
for Laska
RECORDER'S NAME AND SIGNATURE

Picture 1.a The judging Summary Sheet of woman race

2 2 of 2		DATE		EVENT		Posedradý Walking 2010												CHIEF JUDGE'S NAME AND SIGNATURE		OFFICIAL'S SIGNATURE		TIME		CLASSIFICATION		RANKING AND CLASSIFICATION		
		10.4.2010		10km + 20 km Woman		Milošlav Lapka																						
		10.4.2010		10km + 20 km Woman		Milošlav Lapka																						
Number	1	2		3		4		5		6		7		8		OFFICIAL'S SIGNATURE		TIME		CLASSIFICATION		RANKING AND CLASSIFICATION						
Atlete's Number	Country	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish					
97			16:26		16:03		16:03		16:03		16:03		16:03		16:03		16:03		16:03		16:03		16:03		0	3	0	
106					14:52																					1	0	0
89					14:52																					1	0	0
167					14:57																					1	0	0
162							14:59																			1	0	0
88											14:29															1	0	0
104													16:06													0	1	0
85															14:53											0	1	0
																										0	0	0
																										0	0	0
																										0	0	0
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																										0	0	0
																										0	0	0
																										0	0	0
CHECK PAGE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CHECK TOTAL	2	0	5	3	1	2	8	3	2	2	3	2	0	0	5	4	4	3	4	4	1	5	4	0	0	3	28	23

RECORDER'S NAME AND SIGNATURE

Picture 1.b The judging Summary Sheet of woman race



Picture 2. The graph of non-linear consistency for woman race

1		DATE		EVENT		10km + 20 km Men		CHIEF JUDGE'S NAME AND SIGNATURE																					
1 of 3		10.4.2010						Miloslav Lapka																					
Judge's Name Country	A	B	TRK	B	NSL	U	U	CE	D	D	POK	U	U	CE	H	H	CE	Chief Judge	DQ	5G	RC	RC							
	Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Officer's Name	DQ	Time	~	RC							
24	35,39																			15,14		1	3						
22																				15,08		1	0						
40					35,10									35,07						15,10		3	1						
140	35,13													35,07						15,07		1	1						
143														35,07						15,10		0	1						
18	35,17													35,07						15,10		2	0						
127									35,36					35,23						15,27		1	2						
19					35,13	35,22	35,49							35,32						15,15		3	2						
3					35,37	35,40	36,16							35,24						15,25		0	3						
27					35,30					35,47	35,09			35,33						15,33		1	3						
137					35,24	35,30								35,15						15,15		2	0						
16							35,12															1	0						
122	35,36													35,22						15,26		2	0						
11					35,38	35,35								35,28						15,32		2	1						
142														35,27						15,32		0	0						
CHECK PAGE		~	<	RC	~	<	RC	~	<	RC	~	<	RC	~	<	RC	~	<	RC	DO	CHU	DQ	Page	~	RC				
CHECK TOTAL		0	1	5	3	5	6	7	4	3	4	6	2	0	1	12	3	5	12	7	8	4	7	5	0	4	42	33	35

Jim Lapka
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Picture 3.a The judging Summary Sheet of man race

2		DATE		EVENT		10km + 20 km Men		CHIEF JUDGE'S NAME AND SIGNATURE																					
2 of 3		10.4.2010						Miloslav Lapka																					
Judge's Name Country	A	B	TRK	B	NSL	U	U	CE	D	D	POK	U	U	CE	H	H	CE	Chief Judge	DQ	5G	RC	RC							
	Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Officer's Name	DQ	Time	~	RC							
14																				15,17		0	2						
136						35,42	35,32	35,47						35,36						15,30		2	0						
145														35,37	35,41					15,47		0	2						
2						36,10	36,23													16,30		1	1						
37														35,09	35,02					15,10		2	0						
29	35,08													35,02						15,10		0	1						
17						35,09		35,08														0	2						
20					35,17				36,24											16,23		3	0						
31					35,39		35,11		35,46					36,12								0	4						
130					35,34																	1	0						
4								35,26														3	0						
12								36,23												16,28		1	1						
39								35,30														1	0						
9									35,24											15,46		2	0						
1									35,30													1	0						
CHECK PAGE		~	<	RC	~	<	RC	~	<	RC	~	<	RC	~	<	RC	~	<	RC	DO	CHU	DQ	Page	~	RC				
CHECK TOTAL		0	1	5	3	5	6	7	4	3	4	6	2	0	1	12	3	5	12	7	8	4	7	5	0	4	42	33	35

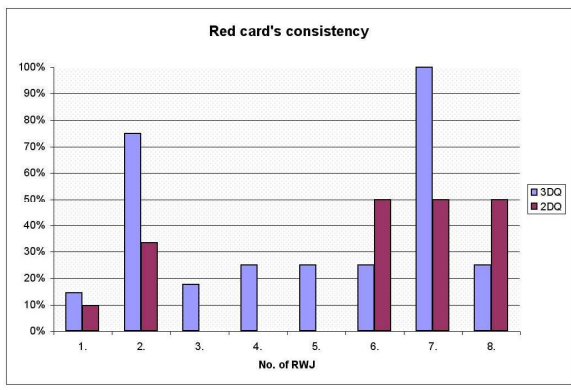
Jim Lapka
RECORDER'S NAME AND SIGNATURE

Picture 3.b The judging Summary Sheet of man race

3 of 3		DATE: 10-1-2010		EVENT: 10km + 20 km Men		CHIEF JUDGE'S NAME AND SIGNATURE: Podlody Walking 2010																																																
Judge's Name (PRINT)		A		B		C		D		E		F		G		H		I		J		K		L		M		N		O		P		Q		R		S		T		U		V		W		X		Y		Z		
Number	1		2		3		4		5		6		7		8		Chief Judge		DO Violation		CHECKED		Comments		Penalty		Ineligibility		RE		RE		RE		RE		RE		RE		RE		RE		RE									
Address Number	N		A		B		C		D		E		F		G		H		I		J		K		L		M		N		O		P		Q		R		S		T		U		V		W		X		Y		Z	
Rank	N		A		B		C		D		E		F		G		H		I		J		K		L		M		N		O		P		Q		R		S		T		U		V		W		X		Y		Z	
Time	N		A		B		C		D		E		F		G		H		I		J		K		L		M		N		O		P		Q		R		S		T		U		V		W		X		Y		Z	
Diff	N		A		B		C		D		E		F		G		H		I		J		K		L		M		N		O		P		Q		R		S		T		U		V		W		X		Y		Z	
Penalty	N		A		B		C		D		E		F		G		H		I		J		K		L		M		N		O		P		Q		R		S		T		U		V		W		X		Y		Z	
RE	N		A		B		C		D		E		F		G		H		I		J		K		L		M		N		O		P		Q		R		S		T		U		V		W		X		Y		Z	

JULIAŠ
RECORDEE'S NAME AND SIGNATURE

Picture 3.c The judging Summary Sheet of man race



Picture 4. The graph of non-linear consistency for man race

The comments on the examples: five judges from the number of eight reached very good DQ consistency and two of them excellent consistency in woman race. Looking at the man race, the rate is worse, two judges reached the excellent consistency again, but the rest of 6 judges reached the only poor consistency. On the other hand, it is very good that none of them is without any contributing to DQ. Looking at the Judging Summary Sheet form, you can see that an average of RC sent do not play any role for the rate of consistency (the judge no 1 for example reached worse scoring with 5 RC than the judge no 3 with 2 RC sent). The judge No 5 is good example how important it is to deliver individual record card to unable to compare all the cautions with the other judges. In our case his individual record card is empty because of delivering his record card in time. Of course, all his red cards are recorded, because of the on-line working recorder and the control program.

Outcomes: How to implement non-linear model?

Going back to demands on the ideal model, we can see

- Individual evaluation is possible and clearly visible in a graphic form.
- Empirical construction of the model avoids the disadvantage connected with linear consistency.
- Model can response to the level of race and number of participants by changing the parameters.
- Just after completing the Judging Summary Sheet the result of DQ consistency and double consistency are available.
- Non-linear model like a program is integrated into the Judging Summary Sheet (in excel). It can be friendly used without any requirements: you can choose whether you want to print the graph of consistency or not.

The implementation requires carefully filled and checked the Judging Summary Sheet. There are the data for the model. The Judging Summary Sheet itself is very important document and any evaluation of consistency without it is not objective. DQ and double consistency can be considered as a high development of the Judging Summary Sheet. We use the Judging Summary Sheet based on the excel file, with a closed cells which does not allow to change any record, if you are not authorized person and more than it, it allows manager of Posting Board to control the correct number of RD

and DQ all the time. The Judging Summary Sheet controls itself with a program controlled correct syntax of every line and cell. It means, if there occur two red cards sent on the same walkers by one judge, it is impossible to record it in the Judging Summary Sheet – error. If 3 red cards are sent to one athlete without DQ, announcement about this occurs in proper cell etc. Now, after many testing is the Judging Summary Sheet with the program of consistency available from the authors of this study for the right using in every race walking competitions as indicated in table 3.

Conclusion

The problem of consistency in race walking judging is the problem of future existence and development of race walking. Behind the statistics methods how to calculate consistency in judging lies an ethical question about responsibility and professional manners of race walking judges.

There are two kinds of consistency: qualitative and quantitative. Both are naturally used in race walking judging and organization, but as regards theoretical principles there are just at the beginning. On the other hand, what is clearly visible for TV spectators, coaches and athletes, is just consistency or inconsistency of judging.

We have tried to bring an overview of qualitative consistency in race walking by using the general definition: Qualitative consistency in race walking can be defined like a consistency of opinion, acting and communication of the judges. Six categories fit to the definition: Punctuality, Concentration, Behavior, Independency, Team communication, Athletes communication. Formalization of these categories is relatively easy; the question is who could evaluate it? Two persons are appropriate for this from their official position during the competitions: the Chief Judge and the Technical delegate. We consider the qualitative consistency to be an important part of ethical behavior of race walking judges. The formalization and an attempt to evaluate this consistency could help the family of race walking judges as well as the walkers and coaches to increase the professional level of our international race walking competitions.

The qualitative consistency is based on two main approaches: linear and non-linear.

The linear approach is used like calculating average and simple linear consistency. Every method has its advantages and disadvantages, discussed

in this study. The great disadvantage is a possibility to increase the individual consistency by “calculation red cards activity”, which means the more red cards are sent, the higher probability of consistency. There are missing variables in the formula 1 and formula 2 using for the construction of the linear consistency. There are some attempts to correct this by combination of both formulas, but anyway, we cannot consider it as a non/linear model. The studies dealing with the problem of consistency are based on the relatively great pool of data coming from many national as well as international competitions.

For our purpose - practical implementation of the model which avoids the disadvantage of the linear model will be used for individual calculating of consistency – we need more developed model based on the empirical experience. In real competition we get 6 variables:

- Total no of RC sent by individual judge
- No of RC sent by individual judge on DQ walkers – consistency with at least 2 and more other RC , we will call it *DQ consistency*
- No of RC sent by individual judge together with other one - 2 RC consistency, we will call it *double consistency*
- No of RC sent by individual judge with no consistency - we will call it *single RC*
- Total no of DQ walkers

We tested DQ consistency formula $\left(\frac{RC_{dq}}{DQ_t} * \frac{1}{\sqrt{RC_i}} \right) * 100$ with extreme

values. This formula seems to be the good background for the implementation of program into the Judging Summary Sheet. The formula can be modified according to the number of participating athletes and level of competitions. In fact, this is the advanced Judging Summary Sheet, including the friendly used program, which can be used in every international and national competition (Miloslav and Jan Lapka copyright). This Judging Summary Sheet with the calculating of non-linear consistency is available for the right use in race walking competitions under the permission of the authors.

However, the best program cannot replace good national and international judges as well as good coaches and athletes in race walking competitions all

over the world. On the other hand, the problem of consistency is the real problem of race walking from the early history of this sport. Every evaluation of qualitative as well as quantitative consistency should be provided correctly with the aim to help race walking, to increase the number of experienced judges. The old tradition combined with a modern method how to conceptualize the problem of consistency seems to be the best way for the future of our sport.

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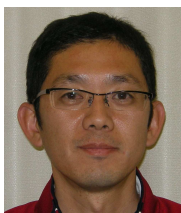
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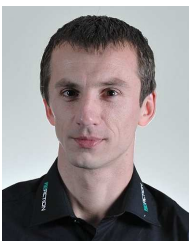
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