Opportunities for Breaking 43 Seconds in the Men's 400m

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ABSTRACT

Wayde van Niekerk's sensational victory and world record in the men's 400m at the 2016 Olympic Games has excited experts and the public with the prospect that he or one of a strong field of rivals could soon run the distance in less than 43 seconds. What will it take in terms of physical capability and effort distribution in the race for someone to achieve this goal? And what effect might the lane draw have on high-level 400m competitions and performances? This study draws on existing data to address these questions and add to the current conversation on the development of the 400m. After reviewing research on the effects of running on the bends, the author examines the velocity dynamics of the men's 400m medallists in selected IAAF World Championships in Athletics over the last two decades and confirms the importance of the 200-300m segment of the race. He also compares van Niekerk's performance with the previous record by Michael Johnson (USA) and suggests that van Niekerk could profit from improving his performance in the 200m if he wishes to achieve faster times over 400m.

AUTHOR

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Introduction

One of the many highlights of the athletics competitions at the 2016 Olympic Games in Rio de Janeiro was the sensational victory of Wayde van Niekerk (RSA) in the men's 400m. His world record time of 43.03 sec sliced 0.15 sec off the highly regarded standard set by Michael Johnson (USA) 17 years earlier at the IAAF World Championships in Athletics in Seville. Behind van Niekerk the entire final field was top class as defending champion Kirani James (GRN) took the silver medal with a time of 43.76 and multiple world champion LaShawn Merritt (USA) took bronze with 43.85 - making it only the second race in history with three under 44 seconds - and the athletes finishing fourth through eighth all recorded the best ever times for their places.

The key moment in the Rio race appeared to be between 250m and 300m when van Niekerk seemed to edge in front of his rivals for the first time. All three of the medallists were flying as they reached 300m ahead of the 31.66 pace set by Johnson in his record run but clearly van Niekerk had distributed his efforts most effectively as he pulled away in the final 100m.

Van Niekerk's performance was all the more notable because he ran in lane 8, which is usually considered disadvantageous as the athletes running there cannot see or pace themselves off of any of their competitors. Interestingly, he was not the first athlete to win the Olympic 400m title with a world record from the outside lane. In 1924 Eric Liddle (GBR) took the gold medal with a time of 47.6 sec from the outside lane 6 on a 500m track (the last time the Olympic Games was staged on a track other than 400m).

The fantastic race in Rio immediately raised a number of questions among coaches and theoreticians working with 400m runners. First, could it be that running in the lane 8 with its more gentle curves is actually an advantage? Second, is there an ideal model for effort distribution? Third, what are the prospects for seeing van Niekerk or one of his rivals dipping under 43 seconds in the near future?

The aim of the present study was to add to the current conversation about the 400m by using existing data to address these questions. The following objectives were set:

1. To review the current knowledge on bend running and how it might apply to the 400m.
2. To analyse the dynamics of running velocity of elite male athletes in the 400m.
3. To evaluate effort distribution required for top results in the 400m using correlation analysis between variables of each 50m segment and the result achieved by elite male athletes.
4. To make a comparison between the times for each 100m segment in the world records of Johnson and van Niekerk.
5. To outline the peculiarities in effort distribution for achieving of top results.

Methods

For the discussion on bend running a search of currently available literature was made and the key points are summarised in the results section below.

For the discussion on running velocity dynamics and effort distribution, the performances of the medallists in three selected IAAF World Championships in Athletics - Athens (1997), Seville (1999) and Berlin (2009) - was analysed (the data covers nine performances and eight athletes as Johnson is included twice, having won the world championships in both 1997 and 1999). This relatively small data set was chosen mainly for its availability but it is assumed that the sample is representative of the very top 400m runners of the last two decades.

From the performances in the data set the times and running velocity for each of the eight 50m segments of the distance are examined. We applied correlation analysis to detect the relationships between the variables of each segment and the performance achieved. The mean values of the variables obtained were then compared with those achieved by Johnson in his 1999 world record performance as well with the split times for the 100m segments of van Niekerk's record run in Rio.

Results and Discussion

Bend running

JAIN[14], ALEXANDROV & LUCHT[1], GREENE[13], BEHNCKE[2] and MORTON[15] have made statistical studies based on mathematical models to compare the best times achieved in straight line running with those run on a bend. GREENE[13] found that a run on a bend with a radius of 38.5m is 0.37 sec slower than on the straight while BEHNCKE[2] recorded a difference as -0.324 sec for the same radius. Before that, JAIN[14] calculated a difference of -0.4 sec without providing details about the radius of the curve.

In their theoretical model USHERWOOD & WILSON[19] found that the time of foot contact increases in bend running due to the additional requirement to overcome centrifugal force and that subsequently velocity decreases. Similar conclusions were reached by CHANG & KRAM[3], who used a small radius (up to 6m) and stated that these forces should not be neglected as they are relatively big and a limiting factor of running velocity.

Studying the effect of different radii on the change of biomechanical indicators, CHURCHILL et al.[4, 5, 6, 7, 8, 9] showed that there is a significant decrease (2.3%) in the mean velocity both of the left and right leg strides during bend running in comparison to running on the straight. Their results showed substantial differences in contact time, stride length and stride frequency, and in the mechanics of movement of the left knee and ankle due to the differences in the bend radius. Like RYAN & HARRISON[17], who studied the effect the of the bends of indoor tracks, they supposed that the changes in contact time and other parameters are due to the centripetal force.

Based on the literature cited above, and personal coaching experience, there is little doubt that the lane draw has an effect on performance in races run in lanes on an indoor track and it can be concluded that that it could even influence 400m performance on an outdoor track. This is due to the increased opportunity the athlete running in larger radius lanes has to maintain velocity in the bend using less effort compared to the tighter inside lanes. From a purely biomechanical point of view, the larger the radius of the bends the better the result one would expect to achieve and this effect would become more noticeable with the greater velocities achieved by the very top competitors.

In fact, there are few experimental studies concerning the effect of the bend radius on running technique in relation of factors like stride length and frequency, time of support, flight phase and running efficiency. Moreover, relatively little attention is paid to the issue of how lanes with different radii affect the running velocity at the moment of going from the bend to the straight. But coaches need to be aware of all these peculiarities in order to help their athletes adjust the running rhythm and distribution of effort during the training process and in order to make proper tactical decisions after learning which lane the athlete will have in a competition. With that said, this is clearly an area where further research would be valuable.

Velocity dynamics and effort distribution

DIMITROV & BOZOV[10] studied the distribution of effort in the 400m both indoors and outdoors and revealed the dynamics of certain indicators. They recorded running velocities at the 100m, 200m, 250m, 300m, 350m and 400m points and examined the changes in stride length and stride frequency. They concluded that one of the reasons for the early appearance of fatigue in Bulgarian 400m runners is a tendency to run the first 100m very quickly compared to the world's best performers, who use only 91-95% of their maximum velocity abilities in this part of the distance. Another finding was that, in the 400m, fatigue first causes a decrease in stride length while stride frequency is maintained but eventually stride frequency is also reduced so that at the end of the race stride length becomes the more important factor for success.

Our analysis of selected top-level performances revealed that the second 50m segment (50-100m) is the fastest of the eight segments of the race (Table 1 and Table 2). The mean time for this segment was the shortest (5.00 sec) and the average velocity was the highest (9.98 $m.s^{-1}$). The next two 50m segments are when the runners try to maintain the velocity reached between 50 and 100m. In spite of this, in the 100-150m segment the average velocity slightly decreased (by 1.51%) to 98.49% of the maximum velocity achieved in second 50m segment and in the 150-200m segment the average velocity fell to 96.39% of the maximum achieved.

It should be noted that the second 100m of the 400m race is the fastest, despite the fact that maximum velocity is achieved during the second 50m segment of the first 100m. In the studied performances the mean time for the first 100m was 11.12 sec compared to 10.29 for the second 100m. The average velocity in the first 100m was 92.53% of what was achieved in the second 100m. The difference is due to the fact that the first 50m of the race includes the start and initial acceleration and the running is done on the bend, while the second 100m segment begins with a flying start and is run almost all on the straight. This analysis confirms the opinions of many experts that during the first 100m top runners reach 91-95% of their velocity abilities.

Table 1: Time characteristics of the 50m segments in the 400m for the medallists at the IAAF World Championships in Athletics in 1997, 1999 and 2009

		Segment (m)								Result (sec)
Athlete	**Year**	**0-50**	**50-100**	**100-150**	**150-200**	**200-250**	**250-300**	**300-350**	**350-400**	**400 m**
		Time (sec)								
M. Johnson (USA)	1999	6.14	4.96	5.00	5.12	5.20	5.24	5.52	6.00	43.18
L. Merritt (USA)	2009	6.08	5.06	5.11	5.24	5.40	5.41	5.68	6.08	44.06
M. Johnson (USA)	1997	6.01	4.98	5.2	5.28	5.28	5.40	5.66	6.14	44.12
D. Kamoga (UGA)	1997	6.23	5.04	5.04	5.02	5.24	5.46	5.78	6.34	44.37
T. Washington (USA)	1997	6.07	5.00	5.10	5.30	5.46	5.4	5.80	6.10	44.39
S. Parrela (BRA)	1999	6.22	4.9	4.91	5.10	5.41	5.56	5.83	6.36	44.29
A. Cardenas (MEX)	1999	6.00	4.99	5.02	5.18	5.39	5.53	5.86	6.34	44.31
Q. Renny (TRI)	2009	6.34	5.20	5.27	5.28	5.48	5.40	5.62	5.94	44.53
J. Wariner (USA)	2009	6.01	4.87	5.15	5.28	5.45	5.48	5.76	6.49	44.60
Average time for 50m (sec)		6.12	5.00	5.09	5.20	5.37	5.43	5.72	6.20	
Average result (sec)		6.12	11.12	16.21	21.41	26.78	32.21	37.93	44.13	
Result at each 100m (sec)		11.12		10.29		10.80		11.92		

In the performances studied, the average running velocity in the third 100m (200-300m) decreased to 95.27% of the maximum velocity achieved in the second 100m (100-200m) segment. The segment 200-250m was run at an average velocity of 9.31 $m.s^{-1}$ and the segment 250-300m at an average velocity of 9.21 $m.s^{-1}$, representing 93.28% and 92.28% of the maximum velocity achieved. Obviously at this point in the race the athletes are beginning to feel the effects of fatigue and how they have distributed their effort, but the fact that the third 100m is run completely on the bend also has an influence on velocity.

The athletes studied covered the last 100m of the race in a mean of 11.92 sec and 85.65% of the maximum average velocity they achieved in the 100-200m segment. It is interesting to analyse the penultimate (300-350m) and last (350-400) 50m segments of the race. As is already known, this part of the race reveals whether the athletes' efforts were distributed most effectively. The average velocities achieved in these segments were 8.736 $m.s^{-1}$ and 8.069 $m.s^{-1}$ respectively, which means that the percentage of maximum velocity achieved was 87.53% and 80.85%, respectively.

Table 2: Dynamics of running velocity ($m.s^{-1}$) in 50m segments of the 400m for the medallists at the IAAF World Championships in Athletics in 1997, 1999 and 2009

		Distance (m)								Mean 400m velocity ($m.sec^{-1}$)
Athletes	**Year**	**0-50**	**50-100**	**100-150**	**150-200**	**200-250**	**250-300**	**300-350**	**350-400**	
		Velocity ($m.sec^{-1}$)								
M. Johnson (USA)	**1999**	8.14	10.08	10.00	9.76	9.61	9.54	9.05	8.33	9.260
L. Merritt (USA)	**2009**	8.22	9.88	9.78	9.54	9.26	9.24	8.80	8.22	9.078
M. Johnson (USA)	**1997**	8.32	10.04	9.61	9.47	9.47	9.26	8.83	8.14	9.066
D. Kamoga (UGA)	**1997**	8.02	9.92	9.92	9.96	9.54	9.15	8.65	7.88	9.015
T. Washington (USA)	**1997**	8.23	10.00	9.80	9.43	9.15	9.26	8.62	8.19	9.011
S. Parrela (BRA)	**1999**	8.03	10.20	10.18	9.80	9.24	8.99	8.57	7.86	9.030
A. Cardenas (MEX)	**1999**	8.33	10.02	9.96	9.65	9.27	9.04	8.53	7.88	9.027
Q. Renny (TRI)	**2009**	7.89	9.62	9.49	9.47	9.12	9.26	8.90	8.42	8.980
J. Wariner (USA)	**2009**	8.32	10.06	9.71	9.47	9.17	9.12	8.67	7.70	8.968
Average velocity for each 50m		8.17	9.986	9.806	9.609	9.31	9.21	8.736	8.069	9.045

Table 3: Correlation coefficients among the 50m segments and the final performance for the medallists at the IAAF World Championships in Athletics in 1997, 1999 and 2009

Segment (m)	0- 50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	**Result 400m**
0-50	1								
50-100	0.576	1							
100-150	0.026	0.561	1						
150-200	-0.374	0.164	0.744	1					
200-200	0.036	0.160	0.328	0.622	1				
250-300	-0.068	-0.255	-0.259	-0.131	0.469	1			
300-350	-0.241	-0.332	-0.377	-0.133	0.409	0.886	1		
350-400	-0.345	-0.685	-0.404	-0.300	0.080	0.758	0.739	1	
Result-400m	0.068	0.138	0.360	0.312	0.714	0.736	0.663	0.457	1

The correlation analysis among all 50m segments and the final result (Table 3) shows that the most important segments for the final result in the 400m are the fifth (200–250m), with a correlation of r=0.714, and the sixth (250-300m), with a correlation of r=0.736. The analysis performed on the dynamics of running velocity revealed that in this part of the race the athletes studied achieved 92.97% and 92.0% respectively of their maximum velocity. A high correlation coefficient was also obtained with the seventh 50m segment (300-350m), correlation r=0.663. It should be noted that the last 50m of the distance (350-400m) shows a moderate correlational coefficient of r=0.457.

The conclusions made above are confirmed by the comparison of the means of the velocity and times of the studied athletes (including Johnson) for each 50m segment with those achieved by Johnson during his 1999 world record (Table 4) shown in Figure 1 and 2. The analysis shows that in the first four 50m segments the differences are minimal, varying between 0.03 and 0.17 $m.s^{-1}$, and for the first 50m the mean value for the studied athletes is actually faster than Johnson's world record run. Then, in the fifth (200-250m) and sixth (250-300m) 50m segments, the difference becomes significant, 0.30 and 0.33 $m.s^{-1}$ respectively. In the seventh (300-350m) and eighth 50m segments

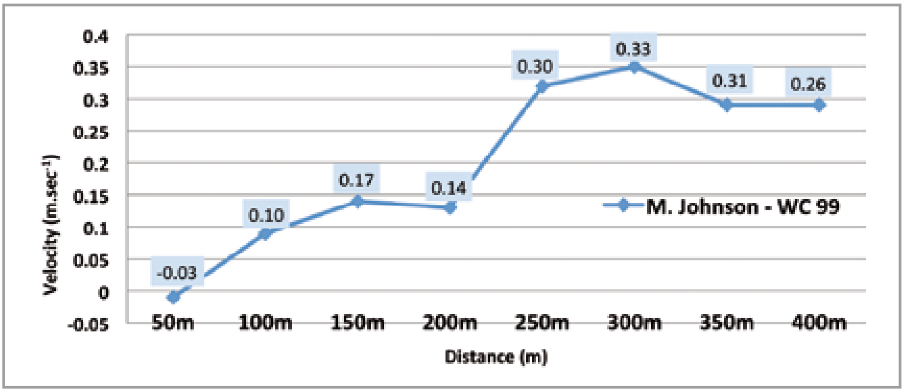

Figure 1: Differences in velocity in each 50m segment in the 400m between the 1999 world record by M. Johnson (43.18 sec.) and averages for the medallists at the IAAF World Championships in Athletics in 1997, 1999 and 2009

Table 4: Comparison of the differences of the means of velocity and times of the studied elite athletes (including Johnson) for each 50m segment with those achieved by Johnson during his 1999 world record

	Distance (m)								
	Year	0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400
	Velocity (m.sec^{-1})								
M. Johnson (USA)	**1999**	8.14	10.08	10.00	9.76	9.61	9.54	9.05	8.33
Mean velocity for each 50m		8.17	9.98	9.83	9.62	9.31	9.21	8.74	8.07
Difference velocity for each 50m		-0.03	0.10	0.17	0.14	0.30	0.33	0.31	0.26
	Time (sec)								
M. Johnson (USA)	**1999**	6.14	4.96	5.00	5.12	5.20	5.24	5.32	6.00
Mean time for each 50m		6.12	5	5.09	5.2	5.37	5.43	5.72	6.2
Difference in time for each 50m		-0.02	0.04	0.09	0.08	0.17	0.29	0.30	0.20

(350-400m) the difference slightly decreases to 0.26 m.s^{-1} but it is still significant. The differences in split times for each 50m segments and especially in the fifth (200-250m) and sixth (250-300m) segments show once again the importance of this part of the race and the possibilities to keep the relative high speed in the next 50m segment (300-350m). These peculiarities underline the high importance of maintaining velocity in the second half of the race.

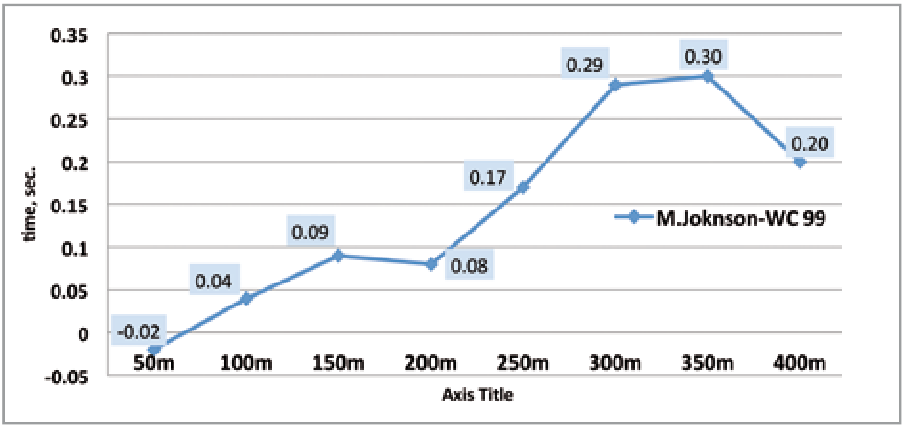

Figure 2: Differences in 50m split times in the 400m between the 1999 world record by M. Johnson (43.18 sec.) and averages for the medallists at the IAAF World Championships in Athletics in 1997, 1999 and 2009

The analyses of the velocity dynamics of the 50m segments, as well as the correlations provide a clear impression about the effort distribution model required for top-level performances. The comparative analysis of the mean 50m split times of the studied athletes and the times of Johnson in his world record race reveal some specific moments that can be used in the training of elite sprinters.

Towards 43 seconds

Data from the BBC on van Niekerk's world record run show 100m splits of 10.7, 9.8, 10.5 and 12.0 sec. Data from ŠKRABA[18] on the same race show similar splits of 10.78. 9.78, 10.50 and 11.99 sec. Comparing the performances of van Niekerk, Johnson and the selected world championship medallists confirms that the second 100m segment is the fastest of the race and that top level 400m runners achieve roughly between 91 and 93% of the average velocity for that segment in the first 100m. It is noteworthy that in the third 100m segment Johnson achieved 96.93% of the velocity of the second segment while the medallists reached 95.28% and that they were able to keep the velocity to 87.85% (Johnson) and 86.41% (medallists) of their maximums in the final 100m segment. Van Niekerk on the other hand achieved a significantly lower 93.1% of his maximum in the third 100m and dropped off to 81.5% in the final 100m segment (Figure 3).

The explanation of the difference between Johnson and van Niekerk could be that in the first 200m of his record run Johnson ran at 91% of personal best over 200m (19.32 sec) while in his record run van Niekerk ran at 97% of his best-ever 200m time (19.94 sec). Being so close to maximum effort presumably had a negative effect in van Niekerk's velocity in the third and fourth 100m segments, despite the fact that is where he appeared to gain the ad vantage on his rivals in Rio.

Behind van Niekerk in the Rio final. James and Merritt, also achieved a high rate of velocity in their first 200m - 99% and 96.6% of their 200m bests respectively (based on unofficial data from ŠKRABA[18]). As mentioned above, all three passed the 300m mark with very fast times, which probably was the main cause of the sharp decline in their velocity in the last 100m.

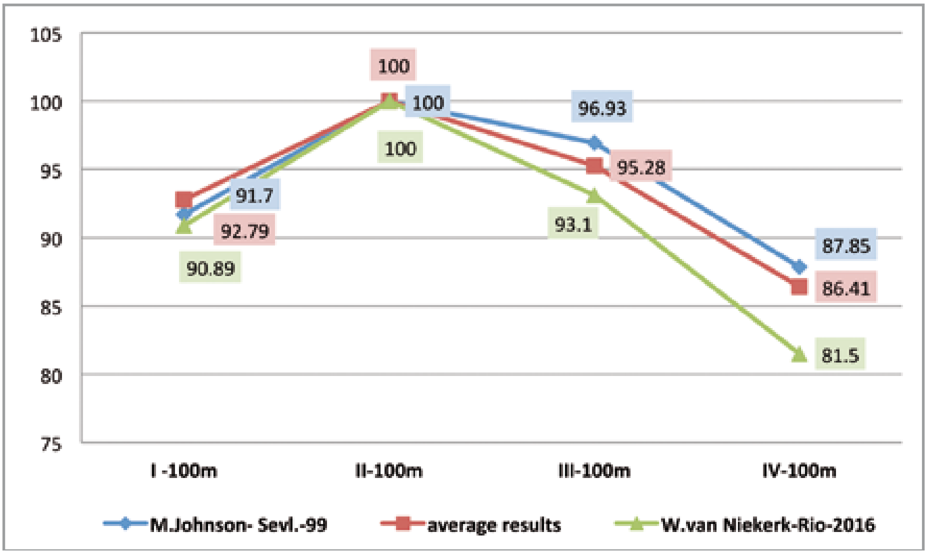

Figure 3: Average velocity in each 100m segment of the 400m (as a percentage of maximum velocity achieved in the race) by M. Johnson in his 1999 world record (43.18) by the medallists at the IAAF World Championships in Athletics in 1997, 1999 and 2009. and by W. van Niekerk in the current world record (43.03)

The prospect for further improvement in the 400m - and thus a shot at breaking 43 seconds - may already be recognised by van Niekerk, who has said that his focus in 2017 will be on improving his maximum velocity by concentrating more on the 100 and 200m events. If successful, this will allow him to run the first 200m with a bigger differential to his maximum effort and thus have more in reserve for the second 200m. James, Merritt and others would do well to consider a similar strategy.

Bend running: reprise

Going back to the effect of the bends on performance in the 400m, I can share a personal experience. As a coach working with Iliya Dzhivondov (BUL), I made a similar analysis of effort distribution prior to the 2000 European Athletics Indoor Championship in Ghent, Belgium, and applied it to the development of his race model. The model included both running rhythm and tactical considerations and took into account the four tight bends of the race on a 200m indoor track. Prioritising the maintenance of velocity in the third 100m segment, we decided that when breaking from the lanes after the second bend of the race it would not be necessary to go down to the inside lane immediately but rather to continue around the third bend in the upper lanes, where the radius of the bend would be greater. We expected that maintaining a higher velocity would outweigh the slightly longer distance run and thus allow Dzhivondov to gain an advantage at the front. I believe that this tactic helped him to win the European title.

Conclusions

1. Analysis of data from different scientific publications allows us to conclude that the lane draw could have an influence on the result in an outdoor 400m. From a purely biomechanical point of view, the larger the radius the better the result achieved. This is due to the opportunity the athlete running in a large radius lane has to maintain velocity in the bend using less effort.

2. The analysis of running velocities for selected elite 400m sprinters showed that the second 100m is the fastest of the four 100m segments of the race but maximum velocity is actually achieved in the 50-100m segment.

3. The differences found between the mean times of selected elite athletes for each 50m segment and the times achieved by Michael Johnson in his 1999 world record provide valuable guidance for a model of distribution of effort for achieving top results in the 400m.

4. The result of the correlation analysis underlined the importance both the fifth (200-250m) and sixth (250-300m) 50m segments, which are run on the bend, and the importance of maintaining high velocity until the finish line for achieving a good result in the 400m.

5. The analysis of the velocity in each 100m segment of Johnson's record, of the surveyed world championships medal winners' performances and of the new world record set by van Niekerk will enable many athletes to improve their effort distribution in the 400m.

6. One of the possible strategies for van Niekerk and others to break 43 sec in the future is to improve their results in the 200m, an approach he has already announce as a task for the next summer season. This will allow them to run the first 200m with a bigger differential to their maximum effort and thus have more in reserve for the second 200m.

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