International Journal of Sports Physiology and Performance, (Ahead of Print)
https://doi.org/10.1123/ijspp.2019-0544

Human Kinetics
BRIEF REPORT

Training Distribution in 1500-m Speed Skating: A Case Study of an Olympic Gold Medalist

Jac Orie, Nico Hofman, Laurentius A. Meerhoff, and Arno Knobbe

At the Olympic level, optimally distributing training intensity is crucial for maximizing performance. ***Purpose:*** The authors evaluated the effect of training-intensity distribution on anaerobic power as a substitute for 1500-m speed-skating performance in the 4 y leading up to an Olympic gold medal. ***Methods***: During the preparation phase of the speed-skating season, anaerobic power was recorded periodically (n = 15) using the mean power (in watts) with a 30-s Wingate test. For each training session in the 4 wk prior to each Wingate test, the volume (in hours), training type (specific, simulation, nonspecific, and strength training), and the rating of perceived exertion (RPE; CR-10) were recorded. ***Results***: Compared with the 8 lowest, the 7 highest-scoring tests were preceded by a significantly ($P < .01$) higher volume of strength training. Furthermore, the RPE distribution of the number of nonspecific training sessions was significantly different ($P < .01$). Significant ($P < .05$) correlations highlighted that a larger nonspecific training volume in the lower intensities RPE 2 ($r = .735$) and 3 ($r = .592$) was associated positively and the medium intensities RPE 4 ($r = -.750$) and 5 ($r = -.579$) negatively with Wingate performance. ***Conclusion***: For the subject, the best results were attained with a high volume of strength training and the bulk of nonspecific training at RPE 2 and 3, and specifically not at the adjoining RPE 4 and 5. These findings are surprising given the aerobic nature of training at RPE 2 and 3 and the importance of anaerobic capacity in this middle-distance event.

Keywords: polarized training, training intensity distribution, experimenting coach, rating of perceived exertion, winter Olympic Games, training optimization

Finding the optimal training-intensity distribution is a pivotal aspect for the performance of elite athletes. In general, endurance athletes may exhibit 2 primary patterns of training-intensity distribution: threshold training and polarized training.[1–3] Threshold training is characterized by training between the first and second lactate threshold. Polarized training, by contrast, is characterized by training below the first lactate or ventilatory threshold (zone 1), or markedly above the second lactate or ventilatory threshold intensity (zone 3), and only to a small degree between both lactate and ventilatory thresholds (zone 2).[1,2] Although previous research has shown that a polarized training distribution is effective for endurance training,[4] only few studies have shown its effectiveness for sports events lasting shorter than 4 min.[5]

The 1500-m speed-skating distance is considered to be a typical middle-distance event in long-track speed skating, for which the current world record is 1:40:17. The typical physiological demands are thus comparable with other middle-distance events such as 200-m swimming (world record is 1:42.00), or 800-m running (world record is 1:40.91). A training regime in speed skating can be categorized into specific (on ice), simulation (off ice; inline speed skating), nonspecific (running and cycling), and strength training. Particularly during the preparation phase of the speed-skating season (May–September), the training is categorized more into simulation, nonspecific, and strength, because ice rinks are closed most of this part of the year. As there are no competition events that constrain training programs during this time of the year, it is the ideal moment to build a good aerobic basis for the upcoming competition phase.

Assessing the effectiveness of the different training methods at the elite level is difficult, as the schedules of such athletes typically leave no room for controlled experiments. As such, little is known about the implications of training distribution in the context of middle-distance speed skating. Recently, the predictive value of anaerobic capacity for middle-distance race performance was shown in speed skating: within a group of elite speed skaters, Wingate test scores were associated with 1500-m speed-skating performance in the subsequent winter.[6] Most likely, this association is so strong because the 1500-m speed skaters use considerable amounts of anaerobic energy in addition to aerobic energy.[7] With these Wingate tests, it is possible to collect data of an elite speed skater that can serve as a proxy for 1500-m performance. As such, the effectiveness of the training intensity distribution can be tested at the elite level, without interfering with the regular training schedule.

With the evidence-based coaching philosophy in mind, the training distribution of our athlete as captured by rate of perceived exertion (RPE)[8,9] was logged in detail and intentionally experimented with over 4 y. Moreover, during the preparation phase of the speed-skating season (May–September), physiological tests were periodically administered. Together, these training logs and physiological tests allow a view into the underpinnings of the preparation of an Olympic gold medalist.

Specifically, we aim to examine the training distribution in the 4 y leading up to a gold medal in the 1500 m at the Olympic Games in 2010. We will first address the research question: "Was the training-intensity distribution experimented with over the years prior to the gold medal in the 2010 Olympic Games?" It is expected that the different training distributions can be shown to fluctuate over the years. Subsequently, we will address the research question: "What are the characteristics of the training distribution prior

The authors are with the Leiden Inst of Advanced Computer Science (LIACS), Leiden University, Leiden, the Netherlands. Orie and Hofman are also with Team Jumbo-Visma Ice, 's Gravenmoer, the Netherlands. Hofman is also with PACA SMA Aalsmeer, Aalsmeer, the Netherlands. Meerhoff (rensmeerhoff@gmail.com) is corresponding author.

to high-, compared with low-scoring Wingate tests?" We expect that the more polarized training distributions yield higher Wingate scores.

Methods

Subject

The case study athlete is a male 1500-m speed-skating Olympic champion. The subject's body height was 1.84 m, mean body weight was 84.5 (0.61) kg, and body fat was 11.3% (1.12%). Written informed consent was provided by the subject and all procedures conformed with the Declaration of Helsinki.

Design

During the preparation phases (May–September) of the 4 y preceding the 2010 Winter Olympic Games, the subject was tested periodically using the Wingate (n = 15), a proxy for 1500-m performance.[10] Prior to these Wingate tests, 4 wk of training logs were included in the analysis. The training logs were analyzed to assess the degree of experimentation that the subject underwent over the years. In addition, the distribution of the training intensity (RPE) will be compared against the Wingate performance.

Methodology

Wingate tests were performed following the same protocol as Orie et al[10] on a mechanically braked bicycle ergometer (Monark 894E; Monark Exercise AB, Vansbro, Sweden) under laboratory conditions. After a 10-min warm-up and 2-min rest, the subject pedaled as fast as possible for 30 s. Over the test duration, mean power (MP) was registered.

For each training session, the intensity, volume, and type of training were recorded. Training intensity was quantified by the RPE, obtained with the Borg CR-10 scale, slightly modified by Foster.[11–14] Training volume (in hours) was defined as time spent on warming up, actual training protocol, and cooling down. A total of 4 different types of training were distinguished: specific (on ice), simulation (off ice; inline speed skating), nonspecific (running and cycling), and strength training.

Statistical Analysis

In the first part of the analysis, we addressed the degree of experimentation in training distribution over the years. The RPE distribution of the frequency in the 4 wk prior to the Wingate tests (averaged per year) was tested with a chi-squared test (RPE unit was considered a categorical variable). In the second part of the analysis, the Wingate outcomes were—based on MP—split into the 7 highest and 8 lowest scoring Wingate tests. We assessed the differences in training volume between the highest and lowest scoring Wingate tests using independent *t* tests. Then, we tested whether the RPE distribution of the frequency in the 4 wk prior to the high- and low-scoring Wingate tests was different using a chi-squared test. Finally, for each of the 15 Wingate tests, the volume per RPE in the preceding 4 wk was correlated with MP using Pearson correlation coefficient (*r*). For all analyses, significance was set at $P < .05$.

Results

As can be seen in Figure 1, the average training volume continuously increased from 2006 to 2009. On average, in the 4 wk prior to the Wingate tests, the total volume increased from 37.9 to 48.9 h. Particularly the volume of nonspecific (from 20.5 to 28.7 h) and strength (from 5.5 to 8.9 h) training has increased over the years, whereas the volume of specific training has decreased somewhat (from 4.9 to 3.8 h).

Moreover, for all types of training combined, the distribution of the frequency of the training sessions per RPE has significantly shifted over the years (χ^2 [27, N = 141] = 22.7, $P < .01$). As can be observed in Figure 2, the lower RPEs occurred more frequently in 2008 and 2009 compared with 2006 and 2007.

The second part of the analysis focuses on the difference between the 7 highest (MP: mean [SD] = 1054 [10] W) and the 8 lowest (MP: mean [SD] = 1023 [12] W) scoring Wingate tests. First of all, the volume in the 4 wk prior to Wingate tests was significantly higher in the high (mean [SD] = 48.3 [6.0] h) compared with the low (mean [SD] = 40.8 [6.1] h) scoring Wingate tests (t[13] = 2.239, $P < .05$). When looking at each of the different training types, only the volume of strength training in the 4 wk prior to Wingate tests was significantly higher in the high (mean [SD] = 8.7 [1.6] h) compared

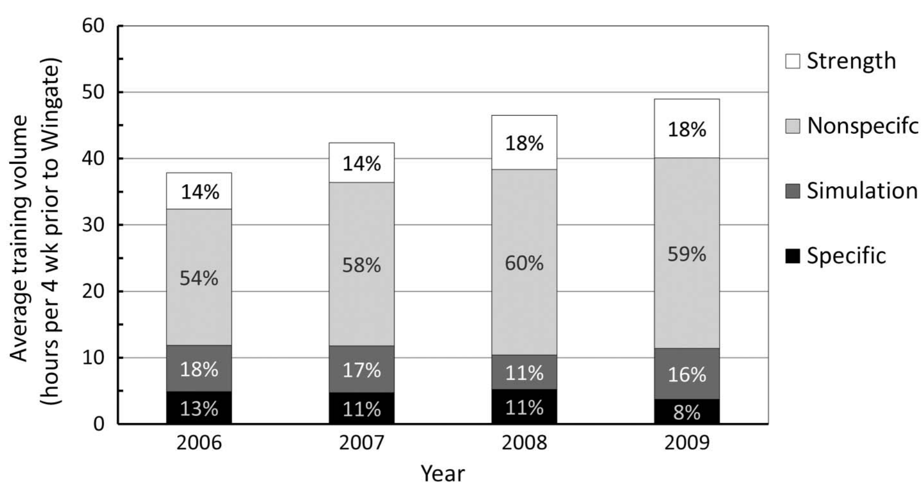

Figure 1 — Training volume in the preparation phase over the years preceding the gold medal at the Olympic Games in 2010. For each year, the average volume (in hours) in the 4 weeks prior to the various Wingate tests is shown, with a specification for each of the types of training.

with the low (mean [SD] = 6.0 [1.7] h) scoring Wingate tests ($t[13] = 3.150$, $P < .01$).

Second, the distribution of the number of training sessions per RPE varied significantly for the high- and low-scoring Wingate tests (χ^2 [9, N = 528] = 22.6, $P < .01$). Moreover, applying the same analysis to each of the different training types revealed that the RPE distribution was only significantly different for the nonspecific training sessions. That is, the number of nonspecific training sessions per RPE was significantly different for the high- and low-scoring Wingate tests (χ^2 [9, N = 255] = 22.6, $P < .01$).

To further explore this effect of RPE distribution for the nonspecific training sessions, the volume of nonspecific training per RPE (averaged in the 4 wk prior to the Wingate tests) is shown in Figure 3. The 7 best Wingate results (solid black line) were associated with a shift to the left of the curve and a higher volume of nonspecific training in RPE 2 and 3. In the 8 lowest Wingate results (solid gray line), the nonspecific training volumes of RPE 4 to 10 were higher, with the exception of RPE 7. Anecdotally, these patterns are exemplified when singling out the best (dashed black line, MP = 1074 W) and worst (dashed gray line, MP = 1002 W) Wingate performances (see dashed line in Figure 3).

Lastly, to get an even closer look into the effect of nonspecific training volume per RPE on Wingate performance as shown in Figure 3, we correlated the nonspecific volume (in hours) with the Wingate performance (MP) for each RPE unit separately. As can be seen in Figure 4, significant correlations were found for RPE 2 ($r = .735$), 3 ($r = .592$), 4 ($r = -.750$), and 5 ($r = -.579$).

Discussion

In this case study, we showed that training intensity distribution can have strong consequences in preparing an athlete for peak performance.

With regard to our first research question, we demonstrated that, as hypothesized, the training intensity distribution of our subject varied significantly over the years. As can be seen in Figure 2, the bulk of the training intensities shifted to the lower RPE in the last 2 y before the Olympic Games. Essentially, this induced a more clear-cut polarization between the lower (RPE < 5) and middle (5 ≤ RPE < 7) RPE units. As our subject clearly underwent changes in training regime over the years, it is informative to examine the effect of training intensity distribution on performance.

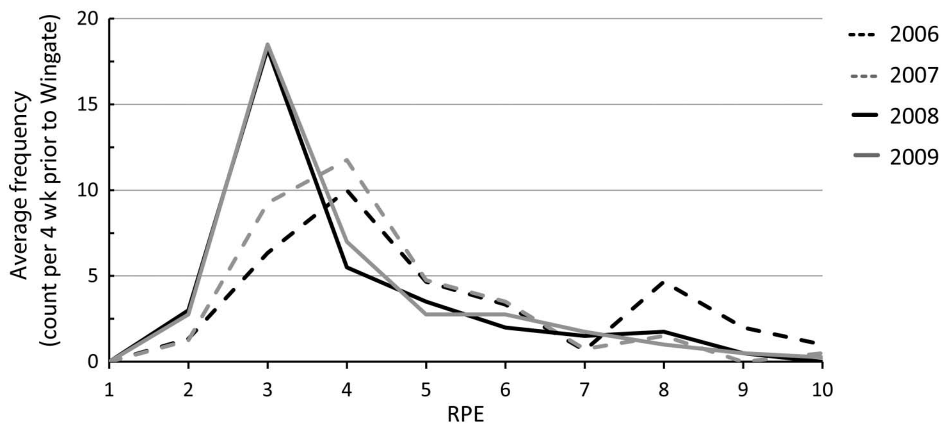

Figure 2 — The year-to-year distributions of the average number of training sessions per RPE unit in the 4 weeks prior to each of the 15 Wingate tests. RPE indicates rating of perceived exertion.

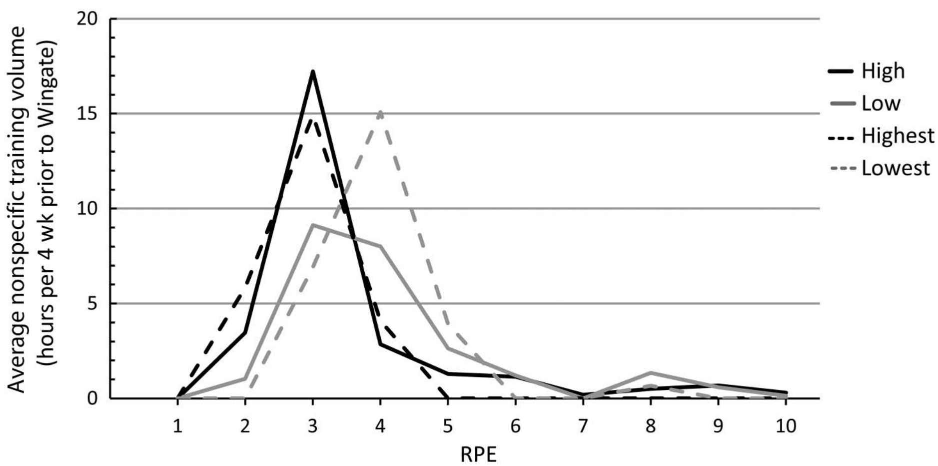

Figure 3 — Average nonspecific training volume RPE distribution in the 4 weeks prior to the 7 highest-scoring (solid black line) and 8 lowest-scoring (solid gray line) Wingate tests. The dashed lines indicate the distributions preceding the single highest and lowest Wingate result. RPE indicates rating of perceived exertion.

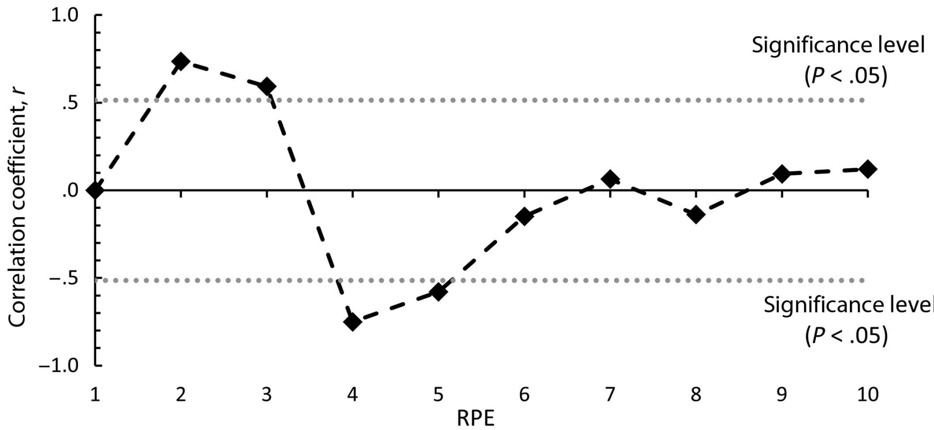

Figure 4 — Pearson correlation coefficients between the nonspecific training volume (in hours) in each of the RPE units and the mean power Wingate scores (in watts). Data points above the upper and below the lower dotted lines are significant ($P < .05$). RPE indicates rating of perceived exertion.

The high Wingate performances were preceded by a larger training volume and more specifically, a large volume of strength training. Note that this larger volume (and not RPE distribution) in strength training indicates that beneficial effects were obtained by increasing the volume (ie, repetitions) of the strength training, and not so much the weight.

When further examining the training distribution per RPE, the high Wingate performances were also characterized by a shift in RPE of the nonspecific training sessions. A visual analysis of Figure 3 shows us that the higher Wingate performances had a higher nonspecific training volume in RPE 3. In comparison, the lower performances had a higher nonspecific training volume in RPE 4 and 5. These beneficial and detrimental effects are corroborated with the correlations between Wingate performance (MP) and nonspecific training volume per RPE unit (see Figure 4). Training intensities RPE 2 and 3 contributed positively and RPE 4 and 5 negatively to Wingate performance.

It stands out that a difference of only one RPE unit has had a strong and opposite effect on training adaptation. Although this is in line with the concept of polarized training (ie, Seiler's "black hole of training"[3]), it is noteworthy that the threshold between zones 1 and 2 was one RPE unit lower for our subject than indicated by the literature.[1] This emphasizes that the volume of the training intensity should be tuned with extreme caution and with respect to the individual athlete. Note that although the movement (ie, cycling) in these sessions may have been "specific" for the Wingate test, the label nonspecific was assigned with respect to speed skating. Furthermore, the physiological demands during the nonspecific training sessions (high volume at RPE 2–3) were not specific for the Wingate test.

The expected positive effect of zone 3 was less elucidated in our results (for all training types). RPE 7 to 10 neither yielded a significant positive nor negative training adaptation. The precise effects of training in zone 3 need to be examined in more detail. The biggest change of the training distribution for our subject was made by avoiding the black hole, rather than by training more in zone 3. Although one has to be cautious with generalizing the findings of this case study, it appeared that for our subject, a good preparation for this middle-distance event required a delicate balance between aerobic (ie, the low RPEs) and anaerobic training. This balance was partially found by increasing the volume of nonspecific training (specifically cycling), as it was easier to maintain low RPEs during this type of training.

Together, these results indicate particularly that the polarization between zone 1 and zone 2 leads to higher performance, partially confirming our hypothesis of our second research question. Above all, this case study highlights that fine-tuning the training intensity for optimal performance is a delicate task.[15] A small difference in training intensity might yield a suboptimal training adaptation.

Practical Applications

The presented findings give a unique insight into the training preparation of an Olympic gold medalist. Interestingly, 1500-m races are performed at RPE 9 and 10, whereas training at these intensities was not found to positively contribute to performance. For our subject, it was best to increase the volume of strength training, increase the volume of nonspecific training at the lower intensities (RPE 2 and 3), and avoid the "black hole" (RPE 4 and 5).

Conclusion

This case study is the first to follow an Olympic speed-skating champion for 4 y leading up to a gold medal. We demonstrate that small adjustments in the training intensity distribution (volume and frequency) has had strong consequences for the preparation of our subject for peak performance.

References

1. Seiler KS, Kjerland GO. Quantifying training intensity distribution in elite endurance athletes: is there evidence for an "optimal" distribution? *Scand J Med Sci Sports*. 2006;16(1):49–56. PubMed ID: 16430681 doi:10.1111/j.1600-0838.2004.00418.x
2. Seiler S. What is best practice for training intensity and duration distribution in endurance athletes? *Int J Sports Physiol Perform*. 2010;5(3):276–291. PubMed ID: 20861519 doi:10.1123/ijspp.5.3.276
3. Esteve-Lanao J, Foster C, Seiler S, et al. Impact of training intensity distribution on performance in endurance athletes. *J Strength Cond Res*. 2007;21(3):943–949. PubMed ID: 17685689
4. Stöggl TL, Sperlich B. The training intensity distribution among well-trained and elite endurance athletes. *Front Physiol*. 2015;6:295.

5. de Koning JJ, Foster C, Lampen J, Hettinga F, Bobbert MF. Experimental evaluation of the power balance model of speed skating. *J Appl Physiol*. 2005;98(1):227–233. PubMed ID: 15591304 doi:10.1152/japplphysiol.01095.2003
6. Hofman N, Orie JNM, Hoozemans MJM, Foster C, de Koning JJ. Wingate test is a strong predictor of 1500 m performance in Elite speed skaters. *Int J Sports Physiol Perform*. 2017;12(10):1288–1292. PubMed ID: 28253027 doi:10.1123/ijspp.2016-0427
7. Orie JNM, Hofman N, de Koning JJ, Foster C. Thirty-eight years of training distribution in Olympic speed skaters. *Int J Sports Physiol Perform*. 2014;9(1):93–99. PubMed ID: 24408352 doi:10.1123/ijspp.2013-0427
8. Day ML, McGuigan MR, Brice G, Foster C. Monitoring exercise intensity during resistance training using the session RPE scale. *J Strength Cond Res*. 2004;18(2):353–358. PubMed ID: 15142026
9. Abe D, Yoshida T, Ueoka H, Sugiyama K, Fukuoka Y. Relationship between perceived exertion and blood lactate concentrations during incremental running test in young females. *BMC Sports Sci Med Rehabil*. 2015;7:5. PubMed ID: 25973209 doi:10.1186/2052-1847-7-5
10. Yu H, Chen X, Zhu W, Cao C. A quasi-experimental study of Chinese top-level speed skaters' training load: threshold versus polarized model. *Int J Sports Physiol Perform*. 2012;7(2):103–112. PubMed ID: 22634959 doi:10.1123/ijspp.7.2.103
11. Foster C, Daines E, Hector L, Snyder AC. Athletic performance in relation to training load. *Wis Med J*. 1996;95(6):370–374. PubMed ID: 8693756
12. Foster C. Monitoring training in athletes with reference to overtraining syndrome. *Med Sci Sports Exerc*. 1998;30(7):1164–1168. PubMed ID: 9662690 doi:10.1097/00005768-199807000-00023
13. Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *J Strength Cond Res*. 2001;15(1):109–115. PubMed ID: 11708692
14. Foster C, Heimann KM, Esten PL, Brice G, Porcari JP. Differences in perceptions of training by coaches and athletes. *S Afr J Med Sci*. 2001;8(2):3–7.
15. Knobbe A, Orie J, Hofman N, van der Burgh B, Cachucho R. Sports analytics for professional speed skating. *Data Min Knowl Discov*. 2017;31(6):1872–1902. doi:10.1007/s10618-017-0512-3