LASE Journal of Sport Science • 2025/1 • Pages **1**–9
https://doi.org/10.25143/lase_joss.v16i1.01

Physiological Effects of High-Intensity Interval Training on Roller Skier Performance: A Systematic Review

Mārcis Jakovičs, *ORCID:* 0000-0003-0112-7989
Inese Pontaga, *ORCID:* 0000-0001-6659-839X

Affiliation: Latvian Academy of Sport Education, Rīga Stradiņš University, Latvia
Address: Brivibas Street 333, Riga, LV 1006, Latvia
E-mail: marcis.jakovics@rsu.lv
Submitted: March 27, 2025

Funded by the European Union NextGenerationEU
2027 National Development Plan

The project "RSU internal and RSU with LSPA external consolidation",
No. 5.2.1.1.i.0/2/24/I/CFLA/005

Abstract

The present systematic review aimed to summarize the research results on the effect of HIIT on qualified roller and cross-country skiers' physiological and performance indicators. The review was performed using digital scientific databases: Web of Science, PubMed, SCOPUS, and the internet platform Research Gate. The following search keywords were used: High-intensity interval training AND roller skiing. After considering eligibility and removing duplicates, only three original research papers on the physiological effects of high-intensity interval training on roller skiers' performance were selected.

The main conclusion from this review was that static interval training protocols such as 4 x 4 minutes for all sorts of endurance are still the preferred choice for HIIT research and have overtaken this field. As looking for research on HIIT in connection with roller skiing we once again find this static approach with 2 to 10 minutes timed intervals with a predetermined total session load. There was only one publication on the dynamic HIIT approach. The numerous meta-analyses' results show that this static approach consistently does not bring positive results: in each investigated HIIT group, we see that the performance and physiological characteristics did not respond to the static HIIT protocols application. Therefore, the topic of dynamic duration HIIT protocols is widely open for investigation in the future.

Keywords: HIIT (High-intensity interval training), roller skier training, sports physiology, gas exchange kinetics

Abbreviations: HIIT: high-intensity interval training, VO2max: maximum oxygen uptake

Introduction

Maximal oxygen consumption (VO2 max) plays an important role in modern Sports Science and Sports Medicine as a functional biomarker for evaluating the functions of the heart and circulatory system (LaMonte, 2005) (Myers, 2002). It is also a widely described marker in clinical medicine for assessing cardiovascular event risks (Kodama, 2009). In cross-country skiers, the result correlates with the peak oxygen consumption; this was discovered by Sandbakk and his colleagues. Analysing the differences between national and international level skiers, it became clear that the efficiency and technique of athletes of both groups are at a similar level. However, the large difference was particularly in the aerobic capacity and peak oxygen consumption, where international level athletes had shown better results, ($p<0.05$) (Sandbakk Ø. H. A., 2016) In cases where this correlation was not directly visible, technical aspects such as efficiency have been shown to compensate for slightly smaller VO2 max in some athletes, as studied in cyclists by Luciano and colleagues (Lucía A., 2002) and in runners Mooses and colleagues (Mooses M., 2015).

While studying the peculiarities of cross-country skiing and the functioning of energy systems for muscle energy supply while practicing this sport, Losengard and his colleagues (2019) have determined the direct connection between athletes' ability to perform short intense repetitions in which an oxygen debt is created, the quick ability to extinguish this debt, and the competition results in cross-country skiing (Losnegard, 2019).

While analysing the literature, high-intensity, maximal oxygen consumption interval training is recognized as an effective way to improve VO2 max. Bacon et al. (2013) confirm this in their meta-analysis. Norwegian studies with the 4x4 interval method introduced by J. Helgerud (2007) have been recognized as more effective. Sloth et al. (2013) also confirmed the effectiveness of VO2 max intensity interval training in the meta-analysis. Gist et al. (2014) observed the same results in their meta-analysis. However, current research still points to the need for further research into high-intensity interval training to find the most effective individual model because not all models work for everyone. Exercises that are effective for one athlete may not be effective for others. Within the wide range that includes all high-intensity interval training, not all are effective at improving maximal oxygen consumption, as Wen (2019) mentioned in her meta-analysis, urging researchers to continue to work and improve their understanding of this training process.

Although literature sources do not provide one exact figure, it is widely recognized that roller skiing takes a large part of cross-country skiers' training volume during the preparation period, especially during the off-season and the season on the treadmill (Per-Øyvind T., 2021).

Also, some athletes concentrate specifically on roller skiing (Jakovics M. &. P., 2023). Considering this, it is vital to understand the effects of high-intensity interval training on roller skiers' performance.

Materials and methods

Search strategy

This literature review was performed using digital scientific databases: Web of Science, PubMed, SCOPUS, and the internet platform Research Gate. The search was carried out before June 2024. No date restriction was considered. The following search keywords were used: High-intensity interval training AND roller skiing.

Eligibility criteria

For inclusion eligibility, the review included all studies where a systemized high-intensity interval training protocol was implemented partially or fully on roller skies. Both randomized and nonrandomized studies were included. Only original peer-reviewed studies written in the English were included. Protocols with no results, reviews, meta-analyses, abstracts, opinion articles, books, statements, letters, editorials, comments, and journal articles that were not peer-reviewed were excluded.

Article selection

All potential studies were registered in an MS Excel sheet, and duplicates were removed. Only studies with measured physiological results characteristics were added to the peer-reviewed journal articles and included in this research. One author, M.J., conducted the selection process. M.J. independently screened the title and abstract of all the studies to determine their eligibility. Then, the full texts of eligible studies were examined. A summary of reviewed studies can be found in Table 1.

Results

Nine articles were found in the PubMed database, 10 in the Web of Science, and 11 in SCOPUS. After considering eligibility and removing duplicates, only three original research papers on the physiological effects of high-intensity interval training on roller skiers' performance were found.

Study characteristics

The characteristics of each of the three studies are represented in Table 1. All the papers included (Rønnestad B. R., 2022), (McGawley K., 2017), (Sandbakk Ø. S. S., 2013) came from the same region – Scandinavia. Sample sizes ranged from 12 to 21 participants. Overall, 53 young adults (16–24 years old) were recruited to participate in the reviewed studies. Two studies (McGawley K., 2017), (Sandbakk Ø. S. S., 2013) included both male and female participants, one study (Rønnestad B. R., 2022) included only the male population. Also, all studies introduced a control group that did not complete the interval training protocol but performed regular moderate-intensity training.

Table 1

Summary of the included studies on high-intensity interval training (HIIT) and roller skier

Study information		Study population				Training information			Control group
First author, year	Country	Sample size (number of participants)	Mean age (years)	VO2max (ml/kg/min)	Sex (% male)	Frequency (sessions per week)	Session load (sets x min)	Training duration (days)	Yes
Bent R Rønnestad (2022)	NOR	12	21.2 ±2.9	69.6 ±6.3	100	5	6 x 5min	6	Yes
Kerry McGawley (2017)	SWE	20	17.3 ± 1.5	67.1 ±2.6	50	9	5 x 4min	7	Yes
Øyvind Sandbakk (2013)	NOR	21	17.5 ±0.5	67.4 ±7.7	57.1	(+2 training sessions)	SIG: 2–4 min for 15–20 min; LIG: 5–10 min for 40–45 min	56	Yes

Abbreviations: SIG – short-interval training group; LIG – long-interval training group

Characteristics of HIIT protocols

All studies introduced typical loading protocols; the athletes performed multiple HIITs, ranging from the shortest 2-minute intervals to as long as 10 minutes. The study carried out by Sandbakk (2013) prescribed both the shortest and longest intervals. In the other two studies, interval length was 5 minutes (Rønnestad B. R., 2022) and 4 minutes (McGawley K., 2017) respectively.

Intervention in two studies (Rønnestad B. R., 2022) (McGawley K., 2017) was carried out in the style of block periodization, where a high amount of sessions was prescribed in a short period or one week: five and nine sessions respectively. The investigation performed by Sandback (2013) was the longest-lasting study: 8 weeks or 56 days of training intervention, where two extra HIIT sessions were added to regular training practices every week.

Physiological and exercise testing

All studies included in this review had pre- and post-intervention tests. The range and scope differ from one study to another, but, in general, all studies paid attention to and examined oxygen consumption and functional markers connected to it. To quantify accumulated time in the load's intensity ≥90% from the VO2 max during the HIIT block, VO2 during the intervals was measured by Ronnestad et al. (2022) on the 1st, 2nd, and 5th HIIT sessions. In their research, the exercise testing protocol consisted of a blood lactate profile test followed by a VO2 max test, both performed using the cross-country (XC) skate skiing technique on roller skis. Pre- and post-testing for the individual XC skier was performed at the same time of day (± 1 h) to avoid the influence of circadian rhythm. VO2 was measured with a sampling time of 30 s, using a computerised metabolic system with a mixing chamber. Capillary blood samples were taken from a fingertip during a 1-minute break between each five minutes bout and analysed for whole blood lactate concentration [La−]. The protocol: after a 10-minute warm-up on the treadmill at an inclination of 3% and a velocity of movement of 12 km/h the test started. A constant inclination of 7% was used during the test. The first 5-minute bout started at a velocity of 10 km/h and increased by 1 km/h for each 5-minute bout until a [La−] above 4.0 mmol·L−1 was measured. Ten minutes after the submaximal test an incremental test was performed, starting at a 7% inclination and a speed of 11 km/h which increased by 1 km/h every minute until exhaustion. Parallel to this, a haematological survey was performed to determine total body haemoglobin mass (Rønnestad B. R., 2022).

McGawley and colleagues (2017) also performed similar pre-and post-testing. They used this protocol: the sub-maximal test was fixed at a 7° gradient and included a 4-minute warm-up followed by four 4-minute continuous stages. Speeds differed for individuals depending on age, sex, and skiing ability, with the warm-up and first stage completed at 5.2–7.0 km/h and increased of either 0.8 or 1.0 km/h per stage to final speeds of 7.6–10.0 km/h. At the end of the sub-maximal test, there was a 1-minute break before participants commenced the maximal test. Depending on age, sex, and ability, the starting speed for the maximal test was 10, 11, or 12 km/h, and the initial gradient was 3° or 4°. The gradient was then increased by 1° every minute, up to a maximum of 9°, after which speed was increased by 0.4 km/h every minute. The test was terminated when participants were unable to continue. Parallel to this, all participants attended the laboratory once during each test period to provide a resting saliva sample to measure cortisol, testosterone, and immunoglobulin A (IgA) concentration, and to complete the 76-question recovery-stress questionnaire for athletes (RESTQ- Sport) and maximal incremental tests and a 600-m TT. Also, resting muscle biopsies were taken from the vastus lateralis 1–3 days before the main test day during each of the three test periods to determine muscle capillary density, fibre area, fibre composition, enzyme activity (citrate synthase (CS), 3-hydroxyacyl CoA dehydrogenase (HAD), and phosphofructokinase (PFK)) or the protein content of VEGF or PGC-1α (McGawley K., 2017).

Sandbakk and colleagues (2013) also performed a functional test. Before and after the intervention, the skiers were tested for time-trial performance on 12-km roller-ski skating and a 7-km hill run. VO2max and oxygen uptake at the ventilatory threshold (VO2VT) were measured during the treadmill running test (Sandbakk Ø. S. S., 2013).

Outcomes of HIIT programs

Table 2 shows the main results and VO2max changes due to training published by different researchers.

Table 2

Summary of relevant results for the reviewed studies on physiological effects of high-intensity interval training on roller skiers' performance

First author, year	Change in VO2max	Control	Main results
Bent R Rønnestad (2022)	N/A	N/A	In well-trained XC skiers, BLOCK (high-intensity interval (HIIT) block) induced superior changes in indicators of endurance performance compared with CON (a time-matched period with the usual training group). Nevertheless, the correlation between the time of the load intensity ≥ 90 % of VO2 max during the HIIT sessions and the main training responses in the BLOCK training group was insignificant (the correlation coefficient was 0.538; p = 0.071).
Kerry McGawley (2017)	Even: Increase by 0,9 ml/kg/min ±2,6, Block: −0,8 ml/kg/min ±2,4	Even is control	Pre- to post-testing revealed no significant differences between EVEN (3 HIT sessions (5 × 4-min of diagonal-stride roller-skiing) were completed at a maximal sustainable intensity each week while low-intensity training LIT was distributed evenly around the HIIT) and BLOCK (the same 9 HIT sessions were completed in the second week while only LIT was completed in the first and third weeks) for changes
Øyvind Sandbakk (2013)	LIG: Improved by 3,7 % ± 1,6 %; SIG: Improved 3,5 % ± 3,2 %	Unchanged	Longer duration intervals improved endurance performance and oxygen uptake at the ventilatory threshold more than shorter intervals.

Endurance performance was improved in two of three studies with a high reliability (Rønnestad B. R., 2022) (Sandbakk Ø. S. S., 2013). McGawley tried to find out if it is better to prescribe intensive block periods of HIIT or to distribute the load more evenly and did not find significant differences. Nevertheless, the group trained with the evenly distributed load achieved a non-significant increase of the VO2 max but the group of intensive block periods of HIIT showed a non-significant reduction of the VO2 max. Pre- to post-testing revealed no significant differences between groups for changes in resting salivary cortisol, testosterone, or IgA, or for changes in muscle capillary density, fibre area, fibre composition, enzyme activity (CS, HAD, and PFK) or the protein content of VEGF or PGC-1α. No differences were observed in the changes in skiing economy or 600-m time-trial performance between interventions. These findings were coupled with no significant differences between the groups for distance covered during HIIT, summated heart rate zone scores, total session ratings of perceived exertion training load, overall perceived recovery, or overall recovery-stress state (McGawley K., 2017).

Based on the data obtained by Sandbakk et al. (2013), after the intervention training period, the long interval training group (LIG) improved 12-km roller ski, 7-km hill run, VO2max, and VO2VT by 6.8 ± 4.0 %, 4.8 ± 2.6 %, 3.7 ± 1.6 %, and 5.8 ± 3.3 %, respectively, from pre- to post-testing, and achieved the improvement in both performance tests and VO2VT when compared with the short interval training group (SIG) and the control group (CG) (all $p < 0.05$). The SIG improved in VO2 max by 3.5 ± 3.2 % from pre- to post-test ($p < 0.05$), whereas the CG remained unchanged.

Ronnestad et al. (2022) determined that the 6-day high-intensity interval (HIIT) block periodisation group (BLOCK) had a larger improvement than conventional training group in the maximal 1-min velocity achieved during the VO2max test (3.1 ± 3.1 % vs. 1.2 ± 1.6 %, respectively; $p = 0.010$) and velocity corresponding to 4 mmol/L blood lactate (3.2 ± 2.9 % vs. 0.6 ± 2.1 %, respectively; $p = 0.024$). During submaximal exercise, the BLOCK group displayed a larger reduction in respiratory exchange ratio, blood lactate concentration, heart rate, and rate of perceived exertion ($p < 0.05$) and a tendency towards less energy expenditure compared to the time-matched period with usual training (CON) group ($p = 0.073$). This research group found that, for all haematological variables, training responses were similar between groups (Rønnestad B. R., 2022).e

Discussion and Conclusions

This systematic review aimed to evaluate the effect of HIIT on qualified roller and cross-country skiers' physiological and performance indicators. The main findings were:

1. The high intensity training HIIT protocols with longer duration intervals improved endurance performance and oxygen uptake at the ventilatory threshold more than shorter intervals.
2. The high-intensity interval (HIIT) block (BLOCK) induced superior changes in indicators of endurance performance (the maximal 1-min velocity achieved during the VO2 max test, velocity corresponding to 4 mmol/L blood lactate, a larger reduction in respiratory exchange ratio, blood lactate concentration, heart rate, and rate of perceived exertion during submaximal exercise) compared with the time-matched period with the usual training group in well-trained the cross-country skiers compared with CON (a time-matched period with the usual training group). Nevertheless, the correlation between the time of the load intensity ≥ 90 % of VO2 max during the HIIT sessions and the main training responses in the BLOCK training group was insignificant (the correlation coefficient was 0.538; $p = 0.071$).
3. In short interventions lasting three weeks, the pre- to post-testing revealed no significant differences between EVEN (3 HIT sessions (5 × 4-min of diagonal-stride roller-skiing) were completed at a maximal sustainable intensity each week while low-intensity training LIT was distributed evenly around the HIIT) and BLOCK

(the same 9 HIT sessions were completed in the second week while only LIT was completed in the first and third weeks) in terms of changes.

Surprisingly, the HIIT intervention was performed for very short terms in the original papers evaluated in this review: two of the three publications (McGawley et al., 2017 and Rønnestad et al, 2022) assessed the interventions with a duration of one week, which is short and considered ineffective by current literature (Wen D., 2019). Therefore, it might not be surprising that no changes in fundamental physiological markers like resting salivary cortisol, testosterone, or IgA, changes in muscle capillary density, fibre area, fibre composition, enzyme activity (CS, HAD, and PFK), or the protein content of VEGF or PGC-1α were observed in the study performed by McGawley et al. (2017).

The main conclusion from this review was that static interval training protocols such as 4x4 minutes introduced by J. Helgerud for all sorts of endurance sports (Helgerud J., 2007) are still the preferred choice for HIIT research and have overtaken this field. While looking for research on HIIT in connection with roller skiing, we once again find this static approach with timed intervals from 2 to 10 minutes with a predetermined total session load. There was only one publication on the dynamic HIIT approach (Jakovics M. P. I., 2022). The numerous meta-analyses' results show that this static approach consistently does not bring positive results: in each investigated HIIT group, we see that the performance and physiological characteristics did not respond to the static HIIT protocols application. (Wen D., 2019). Therefore, the topic of dynamic duration HIIT protocols is widely open for investigation in the future.

Acknowledgements. *The project "RSU internal and RSU with LSPA external consolidation," No. 5.2.1.1.i.0/2/24/I/CFLA/005*

Conflict of interest. *Authors declare no conflict of interest.*

Human and animal rights. *Not applicable.*

Informed consent. *Not applicable.*

References

1. Bacon A.P., Carter, R.E., Ogle, E.A., Joyner, M.J. (2013). VO2max trainability and high intensity interval training in humans: a meta-analysis. PloS One, 8(9): e73182. doi: 10.1371/journal.pone.0073182.
2. Gist, N.F., Fedewa, M.V., Dishman, R.K., Cureton, K.J. (2014). Sprint interval training effects on aerobic capacity: a systematic review and meta-analysis. Sports Medicine, 44(2):269-279. doi: 10.1007/s40279-013-0115-0.
3. Helgerud, J., Høydal, K., Wang, E., Karlsen, T., Berg, P., Bjerkaas, M., Simonsen, T., Helgesen, C., Hjorth, N., Bach, R., Hoff, J. (2007). Aerobic high-intensity intervals improve VO2 max more than moderate training. Medicine & Science in Sports & Exercise, 39(4):665-71. doi: 10.1249/mss.0b013e3180304570.
4. Jakovics M., Pontaga I. Performance and Training Program Characteristics in Elite Junior Female Roller Skier from 2021 Season: a Case Report. Proceedings of the International Scientific Conference "SOCIETY. INTEGRATION. EDUCATION". Rezekne, Latvia, Volume II, May 26th, 2023, P. 647-655. doi: 10.17770/sie2023vol2.7156.

5. Jakovics M., Pontaga I., Arnis V. (2022). Dynamic high intensity interval training protocol effect on peak VO2 in cross country skiers. A preliminary result report. Program and Abstracts of 5th Conference of Baltic Society of Sport Sciences "Challenges and Solutions in Sports Science". 28–29 April 2022, Kaunas, Lithuania, P.66.
6. Kodama, S., Saito, K., Tanaka, S., Maki, M., Yachi, Y., Asumi, M., Sugawara, A., Totsuka, K., Shimano, H., Ohashi, Y., Yamada, N., Sone, H. (2009). Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: A meta-analysis. JAMA, 301(19):2024-2035. doi: 10.1001/jama.2009.681.
7. LaMonte, M.J., Barlow, C.E., Jurca, R., Kampert, J.B., Church, T.S., Blair, S.N. (2005). Cardiorespiratory fitness is inversely associated with the incidence of metabolic syndrome: a prospective study of men and women. Circulation, 112(4):505-512. doi: 10.1161/CIRCULATIONAHA.104.503805.
8. Losnegard, T. (2019). Energy system contribution during competitive cross-country skiing. European Journal of Applied Physiology, 119(8):1675-1690. doi: 10.1007/s00421-019-04158-x.
9. Lucía, A., Hoyos, J., Pérez, M., Santalla, A., Chicharro, J.L. (2002). Inverse relationship between VO2max and economy/efficiency in world-class cyclists. Medicine and Science in Sports and Exercise, 34(12):2079-2084. doi: 10.1249/01.MSS.0000039306.92778.DF.
10. McGawley, K., Juudas, E., Kazior, Z., Ström, K., Blomstrand, E., Hansson, O., Holmberg, H.C. (2017). No additional benefits of block-over evenly-distributed high-intensity interval training within a polarized microcycle. Frontiers in Physiology, 8: article 413. doi: 10.3389/fphys.2017.00413.
11. Mooses, M., Mooses, K., Haile, D.W., Durussel, J., Kaasik, P., Pitsiladis Y.P. (2015). Dissociation between running economy and running performance in elite Kenyan distance runners. Journal of Sports Sciences, 33(2):136-144. doi: 10.1080/02640414.2014.926384.
12. Myers, J., Prakash, M., Froelicher, V., Do, D., Partington, S., Atwood, J.E. (2002). Exercise Capacity and Mortality among Men Referred for Exercise Testing. New England Journal of Medicine, 346(11):793-801. doi: 10.1056/NEJMoa011858.
13. Torvik, P.Ø., Solli, G.S., Sandbakk, Ø. (2021). The Training Characteristics of World-Class Male Long-Distance Cross-Country Skiers. Frontiers in Sports and Active Living, 3: 641389. doi: 10.3389/fspor.2021.641389.
14. Rønnestad, B.R., Bjerkrheim, K.A., Hansen, J., Mølmen, K.S. (2022). A 6-day high-intensity interval microcycle improves indicators of endurance performance in elite cross-country skiers. Frontiers in Sports and Active Living, 4:948127. doi: 10.3389/fspor.2022.948127.
15. Sandbakk Ø., Hegge, A.M., Losnegard, T., Skattebo, Ø., Tønnessen, E., Holmberg, H.C. (2016). The Physiological Capacity of the World's Highest Ranked Female Cross-country Skiers. Medicine and Science in Sports and Exercise, 48(6):1091-1100. doi: 10.1249/MSS.0000000000000862.
16. Sandbakk, Ø., Sandbakk, S.B., Ettema, G., Welde, B. (2013). Effects of intensity and duration in aerobic high-intensity interval training in highly trained junior cross-country skiers. The Journal of Strength & Conditioning Research, 27(7):1974-1980. doi: 10.1519/JSC.0b013e3182752f08.
17. Sloth, M., Sloth, D., Overgaard, K., Dalgas, U. (2013). Effects of sprint interval training on VO2max and aerobic exercise performance: A systematic review and meta-analysis. Scandinavian Journal of Medicine & Science in Sports, 23(6): e341-352. doi: 10.1111/sms.12092.
18. Wen D., Utesch, T., Wu, J., Robertson, S., Liu, J., Hu, G., Chen, H. (2019). Effects of different protocols of high intensity interval training for VO2max improvements in adults: A meta-analysis of randomised controlled trials. Journal of Science and Medicine in Sport, 22(8): 941-947. doi: 10.1016/j.jsams.2019.01.013.