

Oxygen desaturation induced by the static apnea test: A potential performance predictor in elite greco-roman wrestling

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Abstract:

This observational study spans five years of activity (2019-2021 and 2023-2024) with the senior Greco-Roman wrestling national team focusing primarily on XXXII and XXXIII Olympic Games as well as each European and World Championships for Seniors, U23 and U20 categories during the same period. Between various parameters like body-mass index, maximal oxygen uptake, forced vital capacity, relative force index, maximum heart rate and other data, the attention was focused on oxygen desaturation process recorded during a single static apnea. The research data were annually updated using official international results.

The study aimed to identify potential commonalities among athletes who achieved medals in major events during the research period: a restricted number of only four medalists from a total of twenty-six athletes were identified during the research. The data collection process was supported by certified equipment, providing information both during specific efforts and at rest for each subject. For a select group of athletes, across two consecutive Olympic cycles, superior spirometry values and oxygen desaturation patterns during static apnea predicted good results in official Greco-Roman wrestling events.

The analysis of oxygen desaturation offers a new approach to evaluating performance in our sport domain, and the methodology continues to be refined. Findings from this type of study can help trainers identify wrestlers with innate abilities to sustain exhaustive and complex efforts, facilitating the attainment of exceptional results. More recently, training programs can be enhanced with assessments using affordable and reliable equipment adapted to the evolving conditions of sports environments.

Keywords: wrestling performance, oxygen uptake, lung capacity, static apnea, oxygen desaturation

Introduction:

Continental, World Championships, and Olympic Games (OG) are official events used to determine annual rankings. Wrestling efforts are challenging to quantify owing to their mixed-energetic nature, the biomechanical complexity of the sport, and the fact that official rules do not allow heart rate (HR) recordings during bouts. While other sports can collect performance data while official competitions are in progress, this is not possible in United World Wrestling events.

Therefore, success may depend on modelling the training process as closely as possible to formal effort. Some nations have already achieved considerable success through a combination of rigorous training, careful athlete selection, modern training methods, and research investment. As of late 2025, Japan is recognized for excellence in female wrestling (Arakawa, H., Yamashita, D., Arimitsu, T., et al., 2020), while the Islamic Republic of Iran leads Greco-Roman and freestyle rankings (top nations at the Senior World Championships, September 13–21, 2025, Zagreb, CRO).

Currently, wrestlers from the Russian Federation and the Republic of Belarus are excluded from official team rankings at all Championships (United World Wrestling, February 2025). However, these countries continue to represent substantial potential, not only in Greco-Roman style.

This research focuses on several aspects that could explain or even predict exceptional performance at peak of physical condition among wrestlers across two consecutive Olympic training cycles. While numerous metabolic parameters were collected during the program, particular attention was given to the oxygen desaturation process.

Research of this kind in the sports domain arises from the need for innovative selection procedures capable of identifying athletes with innate abilities who may achieve remarkable success in their careers. Obtaining quantified results during training camps using certified equipment proved challenging for the Olympic

technical team. In a complex sport such as Greco-Roman wrestling, it is not always easy to explain every success or understand every failure (Gierczuk, D., Sagowski, J., 2021). Therefore, accurate individual data for each team member became a central focus of this research.

The information provided at the end of each survey period helped both trainers and athletes better understand the body's metabolic responses to specific efforts. Additionally, the cost of the survey program was a consideration: the equipment needed to be affordable, reliable, and functional in virtually all training environments, including high-altitude settings.

The context of activity during the data collection was a permanent adaptation to the changing conditions. It was a program managed outside laboratory but performed inside training camps, with limited capacities. The study-group dynamic was not in control for the researcher: new entries inside teams, replacements, injuries, changing partners, restricted areas was only few details that has to be challenged. Referring to 2020 Tokyo OG, the pandemic restriction was an additional perturbator performance factor for everyone, not only for the study group. During the COVID-19 pandemic, the importance of oxygen saturation (SpO₂) measurements in detecting illness symptoms was emphasized by several researchers (Nguyen, L.S., Helias, M., Raia, L., et al., 2022).

Silent hypoxia or asymptomatic hypoxia was associated with COVID-19, and pulse oximeter monitoring was highly recommended by medical specialists as an efficient, reliable, and non-invasive method (Conti, S., Pariza, P., Wolters, A., 2025). However, the oxygen saturation survey in this study targeted a distinct goal: to explore its association with significant official results for wrestlers capable of maintaining apnea for as long as possible, thereby inducing a decrease in oxygen levels during recording - a potential indicator of their ability to tolerate discomfort by focusing distributive attention on the task while desaturation occurred. The researcher's initial investigations into the relationship between SpO₂ and HR began several years ago (Moștofleu, F., 2011, 2016). Over time, these two parameters were analyzed in larger study groups, across varied environments and with different equipment configurations.

In the research network, there are notable studies examining oxygen desaturation in diving activities (Schagatay, E., Richardson, M. X., Lodin-Sundstrom, A., 2012) or the effects of apnea training on aerobic and anaerobic performance (de Asis-Fernandez, F. et al., 2022); however, few studies have addressed this issue in the context of wrestling. This study builds on previous research, applying these findings to the sport domain to help explain performance in Greco-Roman wrestling.

The equipment

First item: maximal oxygen uptake (VO₂ max)

For HR data collection [maximum heart rate (HRmax) and resting heart rate (RHR)], various Polar devices were used, including the M430 and V800 watches, H10 sensors, and the Polar Beat app (Polar Electro Oy, Kempele, Finland). A key challenge was configuring the equipment for high-intensity contact between partners to minimize data loss and accurately identify each subject's HRmax peak. HR data were collected during various efforts, including a 400 m run, specific wrestling exercises, adapted football/basketball games, uphill running, and specific strength training, with a written protocol recorded for each session.

The highest HR value for each subject was subsequently entered into the Fitness Test Program to calculate VO₂max. The Fitness Test itself was performed in a supine position during total rest at the end of each research session.

This type of non-exercise test predicts VO₂max and incorporates resting measurements and HR variability in accordance with personal information (Polar Research and Technology, 2019).

Second item: Forced Vital Capacity (FVC)

Previous research (Moștofleu, F., 2018, 2024) and periodic internal wrestling reports highlighted the importance of FVC measurements as indicators of athletes' superior respiratory adaptation to physical activity. Spirometry was performed using the Spirobank II device (Medical International Research, Rome, Italy), with results automatically interpreted using the NHANES III database as in Figure 1. Tests were performed on rest days, primarily Saturdays and Sundays, in a controlled environment.

The FVC test was performed as follows: after a deep inhalation, the subject performed a complete exhalation followed by a second inhalation. A nose clip was used to prevent airflow through the nostrils, while a disposable turbine was inserted into device.

Each subject performed two to three attempts per session, with the best result recorded. An FVC value exceeding 100% was interpreted as a positive adaptation of the respiratory system to the specific demands of wrestling. Periodic spirometry measurements also served as an important indicator of subjects' health during the pandemic (Chai, C.S., Bin Ibrahim, M.A., Binti Azhar, N.A., et al., 2024)

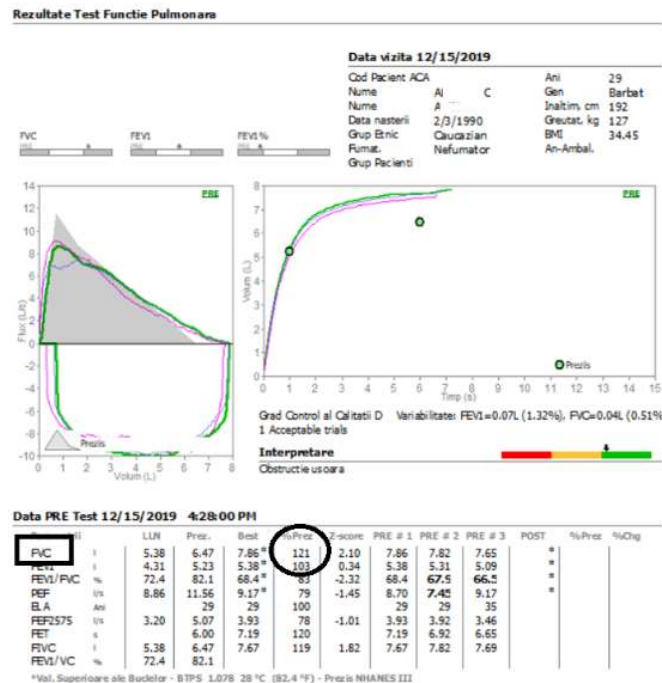


Figure 1: Sample of initial spirometry data with superior predicted value (FVC = 121 %) / S12

Third item: SpO₂ (oxygen saturation)

The Beurer PO 80 pulse oximeter manual specifies a 2% error tolerance for SpO₂ measurements (Beurer GmbH, Ulm, Germany); accordingly, all changes exceeding 2% were considered significant for this study.

The test aimed to identify subjects capable of maintaining a single static apnea for as long as possible, thereby inducing oxygen desaturation while focusing on a video displayed on a screen. The device was connected to a computer via USB, and participants were instructed to avoid uncontrolled arm movements to prevent data loss. Measurements were recorded in a controlled environment with subjects in a seated position to minimize equipment interference, ensure accurate data storage and allow reliable retrieval for follow-up analyses in subsequent years.

Description procedure for Static Apnea Test (SAT):

Initially, none of the subjects were familiar with the procedure; however, those who continued training year after year became accustomed to it. The SAT was designed to partially replicate real wrestling situations, in which athletes must overcome discomfort caused by high-intensity effort, painful pressure on the ribs, restricted breathing, and muscle fatigue (Fletcher, J., 2025). At the same time, wrestlers were required to maintain distributive attention, responding to trainers' audio cues from a distance while simultaneously reacting to visual triggers. In high-intensity, high-stakes encounters, every detail can be critical.

The test was progressively made more complex by introducing visual and audio stimuli that participants had to identify instantly during the apnea and later recall in a questionnaire. Subjects were required to rapidly recognize specific Greco-Roman wrestling images (in the blink of an eye) and recall audio cues embedded in the video, which were frequently updated with new stimuli.

All subjects performed the test in a seated, ergonomically comfortable position in front of a screen, with a nose clip to prevent airflow. Headphones were worn, and a pulse oximeter attached to the finger recorded data to a computer. The test was timed, beginning with a deep inhalation and ending after the consecutive inhalation, with the exhalation period also recorded. To account for potential data delays, the pulse oximeter remained attached for several minutes after the apnea to capture any subsequent saturation or desaturation events.

At the end of the test and after disconnecting the pulse oximeter, subjects completed a questionnaire to assess their ability to recognize the specific audio and visual stimuli embedded in the video. Longer static apnea durations and a higher number of correctly identified stimuli indicated better performance. Additionally, the amplitude of oxygen desaturation was recorded.

The SAT was performed once per session, with frequency depending on the athlete's level of sports activity. For example, five subjects completed only a single test before being replaced in the study group, while others completed multiple tests over the years. Subject S12 accumulated the highest number of SAT trials across

the five-year survey, totaling 14 attempts. In 2023, two athletes completed a maximum of five tests each, and in 2020, four athletes completed the maximum number of tests.

The method:

The research was performed as an observational study (Navidi, W., 2015). The researcher did not intervene to optimize subjects' performance and had no control over the study group dynamics, including new entries, ongoing recordings, or team replacements. Only the trainers were able to push athletes to their limits during HRmax collection. Subsequently, HRmax data were used to automatically calculate VO₂max through the Polar Beat/Fitness Test application while subjects were in a supine position.

Additionally, subjects maintained full control during the SAT, HRmax, or FVC tests and were allowed to stop the tests at any time for any reason.

The Premise, Time Table and Participants:

Each athlete was periodically tested (twice per year) in a comprehensive sports medicine environment to determine their qualification as "fit for competition." Any signs of illness incompatible with performance, HR irregularities, or major injuries resulted in removal from official event rosters.

The program I performed was independent of this medical evaluation but aligned with the training schedule. The research was based on the premise that all athletes were in optimal physical condition. The subjects were national wrestling champions in their respective weight categories, carefully selected for the representative team, with some having prior international experience during the peak of their athletic careers.

The oxygen desaturation survey began in December 2019 with a simple timed apnea effort, recorded using observational method without data storage. This approach was sufficient to highlight one subject with a natural aptitude for maintaining prolonged static apnea (Subject S2: breath-holding time of 2:19 with 21% desaturation), even without specific training for the test. Starting in February 2020, resting SpO₂ values were stored electronically, and oxygen desaturation diagrams were recorded a few weeks later.

In March 2020, the sports community expressed concerns regarding the Tokyo 2020 OG preparation schedule, which underwent daily changes and ultimately led to major decisions (International Olympic Committee, 2020, Communiqué, March). With respect to the international wrestling calendar, all events from the Olympic Qualification Tournament in Ottawa (March 2020) to the National Cup of Ukraine (October 2020) were held only in national territories owing to pandemic restrictions. The Tokyo 2020 Olympic Games were subsequently postponed to 2021 year. From the beginning, the focus was on four wrestlers aiming to secure one or two qualification spots for the Tokyo 2020 OG. By the end of the 2019–2021 training cycle, a total of 18 athletes were included in the survey at various stages of training. Some were sparring partners, while others were members of the U23 and U20 national teams, all participating in joint training camps.

Twelve of the 18 wrestlers had the opportunity to compete in Continental or World Championships during the study, and four were included on the starting list for the Olympic Qualification Tournaments in 2021. At the end of the first Olympic cycle, the Romanian Greco-Roman wrestling team secured one qualification spot for the Tokyo OG - no medal earned in that big event. For the Paris 2024 OG, seven of the original 18 athletes from the first Olympic cycle continued training, again aiming for one or two qualification quotas. By the end of the second period, a total of 15 wrestlers had been evaluated at various training stages and environments. Thirteen of these athletes competed at least once in European or World Championships in their age categories, occasionally participating in higher age groups. Five athletes were listed for the Olympic Qualification Tournaments in 2024. At the end of the second Olympic training cycle, the Romanian Greco-Roman wrestling team secured two qualification spots for Paris 2024, though no medals were earned.

Combining participants from both consecutive Olympic training cycles, a total of 26 wrestlers were surveyed as in Figure 2 and multiple tested in various environments – oxygen desaturation records included.

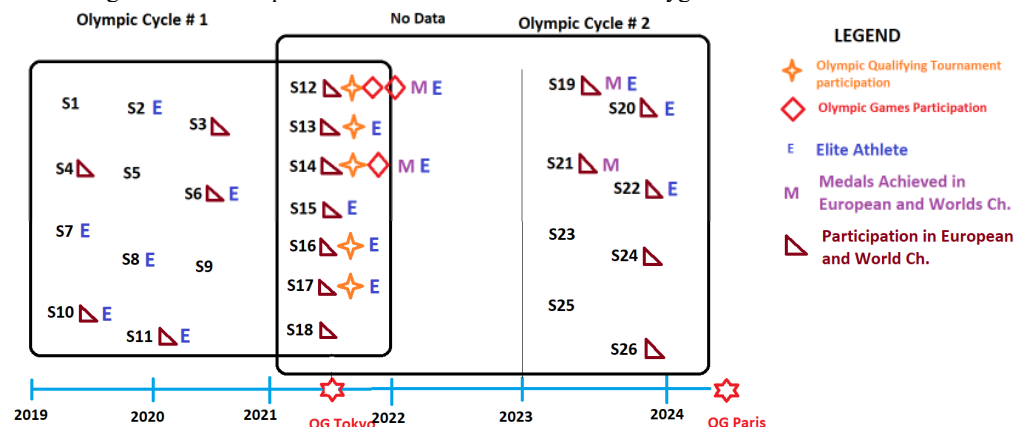


Figure 2: Study group comprising 26 subjects and their participation across two consecutive Olympic cycles

The average age of the participants at the time of first contact was 20.57 years (range 17 to 29, one smoker). All athletes provided written consent to participate in the study. Over the five-year survey, there were 10 distinct moments for initial contact and tests as follows:

December 2019 (4 subjects—all medalists);

February, March, August, September, and November 2020 (10 subjects, 4 medalists);

February and March 2021 (5 subjects, 3 medalists); and

August and November 2023 (7 wrestlers, 3 medalists). In total, 26 athletes were surveyed, of whom 14 had previously won medals at World and European Championships.

Subject S12 was the only athlete to qualify for two consecutive OG during the study period, while S14 was the second athlete submitted for Paris 2024. After the Tokyo Olympics (summer 2021) until spring of 2023, data collection was paused independently of the lead researcher. During the remaining period, 18 of the 26 athletes competed in Continental or World Championships. Only four athletes (S12, S14, S19, S21) earned medals for the national team in major events during the five-year survey.

An elite athlete (EA) status, based on VO_{2max} values as in Figure 3, was assigned at least once to 14 of the subjects (54%). One athlete (S13) consistently received the EA qualificative from the Polar program during the survey period, indicating constant performance. However, in his case, the expectations in major events have not fulfilled.

An important exception is S12, a heavyweight wrestler with a body mass index (BMI) of approximately 35. He was the most frequently tested athlete owing to his long career, including four consecutive Olympic participations. Despite his body structure and metabolic parameters, he never received an EA designation from the Polar Fitness Test application. However, according to sports literature, he can be considered an EA (Epstein, D., 2014, p. 34), having accumulated over 6,000 h of practice from early wrestling initiation until his retirement at age 34 (Trifu, C., 2024).

14/12/2023	▲	67	Elite
20:32		67	Elite
20:12		43	Fair
19:46		40	Fair
13/12/2023	▲	70	Elite
20:45		70	Elite
20:19		63	Elite
20:01		63	Elite
19:41		48	Moderate
16/11/2023	▲	70	Elite
18:22		40	Fair
14:58		60	Very good
14:02		70	Elite

Source: [Polar Flow](#), reproduced with permission from Polar Research (2025)

Figure 3: Sample VO_{2max} report from a high-altitude training camp (2000 m)

SAT data analysis:

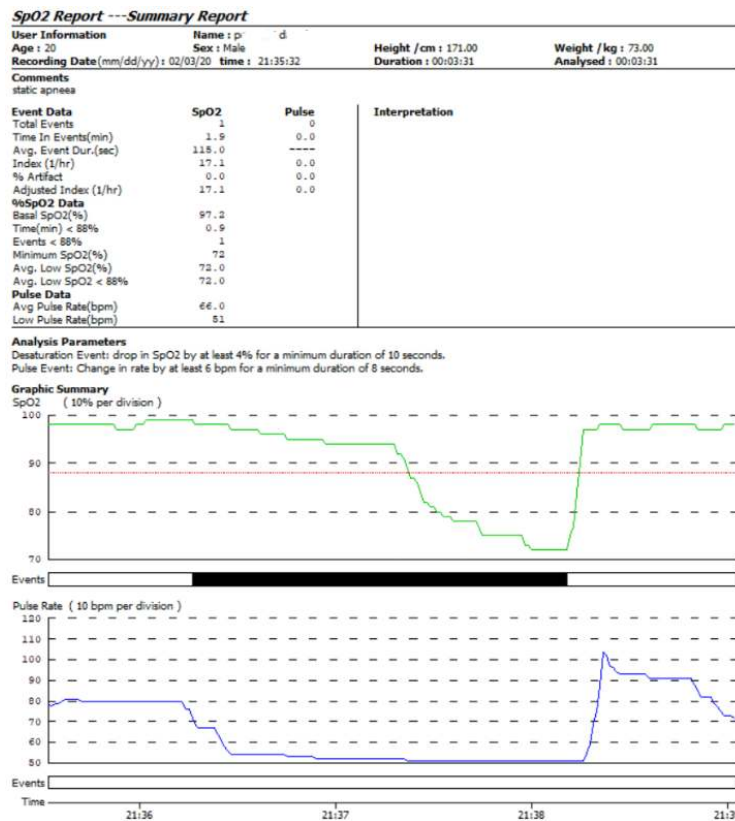
The breath-holding performance of our subjects was modest compared with world record times (Casella, C., 2025). The average SAT time for the entire group was 58 s (range: 35–154 s), with the longest breath-holding time recorded at 2:33.46 / S4.

Three types of SpO_2 graphical patterns can be identified:

Type A: Some subjects were unable to overcome the discomfort caused by prolonged single apnea (the physiological breaking point that triggers excitation of the respiratory muscles; Andersson, J.P.A. & Shagatay, E., 1998) and resumed normal breathing before any desaturation occurred. Oxygen levels remained essentially constant ($\pm 2\%$), even though HR values fluctuated, making the SAT too short to produce desaturation events.

Type B: For certain subjects, pre-respiratory cycles performed before the SAT led to an initial increase in oxygen relative to baseline; however, no subsequent decrease was observed, indicating again that the SAT was too brief.

Type C: In other cases, prolonged apnea combined with focused mental effort produced measurable decreases in SpO_2 , as in Figure 4.



Source: personal dataset

Figure 4: Sample of Type C SpO2 Report (desaturation 25.2%) after 2:02.37 apnea / S2

Metabolic responses varied considerably among wrestlers: some subjects began desaturating after just 40 seconds of breath-holding, while others showed no response even after more than 1 minute of apnea. For example, (S12 – two consecutive qualifications for OG during the survey and four-time Olympian during entire career) exhibited varying apnea durations and oxygen desaturation patterns across different SAT sessions, influenced by fitness level, health status, and mental focus. In his case, all three response (Type A, B, and C) were observed. Another athlete (S14 who qualified for Paris 2024), achieved oxygen desaturation in all 12 attempts across the four-year survey. Eight other subjects (S5, S11, S19, S20, S21, S22, S23, S24, and S26) also demonstrated Type C responses, albeit in fewer attempts. Notably, not every wrestler - regardless of EA status - was able to mobilize sufficiently during the tests to produce a Type C desaturation pattern, highlighting that the procedure was challenging and uncomfortable even for athletes with superior fitness levels.

An interesting observation was that several subjects identified more stimuli in the film during shorter apneas than others who had longer breath-holding times or even higher oxygen desaturation percentages. This was interpreted as a sign of good distributive attention to both audio and visual cues during the SAT. Additionally, the desaturation itself may reflect superior mental mobilization, demonstrating the ability to overcome physical discomfort induced by prolonged breath-holding.

Results

Of the 26 subjects surveyed as in Figure 1 across two consecutive Olympic cycles (14 of whom were previous medalists prior to joining the study group), only four confirmed their competitive value in major events during the research period – not a big proportion. Their performance was supported, as shown in Table 1, by the following parameters:

Table 1 – Forced Vital Capacity, breath-holding time, desaturation and maximal oxygen uptake for the medallists

Subject results	FVC min/max	% SAT min/max	time	SAT min/max	SpO2 min/max	% VO2max min/max
S12	105-129	38.22	1:18.66	< 2% / - 10.2	40-44	fair-moderate
Medal E Ch 2020 Q.A. OG 2020 & 2024				Phase A + B + C		
S14	103-108	40.20	1:08.16	- 2.9 / - 8.3	61-68	very good
Medal E Ch 2021 & 2024 Q.A. OG 2024				Phase C		- elite
S19	114-124	45.62		- 5.8 / - 9.1	70-72	elite
Medals E Ch U-23 & sen 2023 E Ch & World 2024		1:11.92		Phase C		
S21	121 - 129	1:10.76	1:10.86	- 3.8 / - 5.8	52-60	good – very good
Medal E Ch U-20 2023				Phase C		

Conclusions

Achieving medalist status in wrestling does not necessarily correspond to EA classification. VO_2max data collected from all 26 subjects over the study period ranged widely, from fair/moderate to very good/elite qualitative, according to automated Fitness Test predictions. The only four medalists in the research group exhibited a similarly broad spectrum of maximal oxygen uptake, as shown in Table 1.

A breath-holding time around 1:10 was sufficient to produce a Type C oxygen desaturation diagram, which was consistently observed in our four medalists. Three of them recorded SpO_2 decreases during every SAT session, reflecting mental toughness and the ability to endure discomfort long enough for desaturation to occur, as shown in Figure 4.

Regarding the quality of responses in the questionnaires, S14 and S21 ranked among the athletes who recognized the most stimuli - 50% of the medalists, as shown in Figure 5. Their accurate responses were ultimately reflected in strong results in official events. After the five-year survey and various tests, a model of a medalist in the study group of Greco-Roman wrestlers emerges: an athlete (preferable with EA status though not mandatory), capable of maintaining breath-holding for over 1:10 min until SpO_2 begins to decrease. During this period, superior distributive attention allows the athlete to identify the greatest number of combined stimuli while simultaneously producing a Type C SpO_2 diagram. These attributes are further supported by other favorable factors for success, including well-developed wrestling knowledge, extensive sport-life experience, mental toughness, and occasionally an element of fortune.

Oxygen desaturation induced by the Static Apnea Test may serve as a plausible predictor of performance in elite Greco-Roman wrestling, as evidenced by all four medalists presented in Table 1.

This longitudinal and observational study enhanced the understanding of a few outstanding sports performances; in this regard, credit is due first to the athletes themselves and second to any supporting entities.

Conflicts of interest The author declares no conflicts of interest.

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