https://doi.org/10.47183/mes.2026-470

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MODEL CHARACTERISTICS OF FUNCTIONAL FITNESS OF PARALYMPIANS WITH MUSCULOSKELETAL IMPAIRMENTS IN WINTER SPORTS

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Introduction. Within the framework of the State Programme “Development of Physical Culture and Sport”, adaptive physical education and Paralympic sport are actively developing. Under these conditions, developing model characteristics of functional fitness for Paralympic athletes with musculoskeletal impairments (MI) becomes particularly important. The aim is to improve the effectiveness of the training process both at the stage of athletic advancement and during athlete selection.

Objective. Determination of model characteristics of functional performance in Paralympic winter sport athletes with MI for the implementation of sports training during the Olympic cycle up to 2030.

Materials and methods. A retrospective analysis was conducted on 1037 testing protocols for physical performance parameters of 176 Paralympic athletes (2015–2025) competing in winter sports: cross-country skiing, “sitting” category (LW 5/7–12) and “standing” category (LW 2–5/7); sledge hockey, “sitting” category (LW 5/7–12); alpine skiing, “standing” category (LW 2–5/7); wheelchair curling (LW 5/7–12). Functional metrics were determined via an incremental exercise stress test protocol established by the Federal Science Center of Physical Culture and Sport for able-bodied athletes, which was modified for upper-body work using a hand ergometer. For standing cross-country skiers, an incremental test to volitional exhaustion was performed by means of an HP Cosmos treadmill: 3-minute stages with workloads starting at 100 W for both men and women and increasing progressively by 50 W per stage (treadmill incline: 1°). Conversely, sitting athletes underwent an incremental test using a hand ergometer: 3-minute stages with workloads increasing by 20 W starting at 40 W for men and at 20 W for women. The same hand ergometer protocol (3-minute stages; 40 W starting workload, 20 W increments) was applied to Para ice hockey players. For Para alpine skiers and snowboarders, an incremental test to volitional exhaustion was conducted using a Schiller bicycle ergometer (Switzerland): 3-minute stages, with workloads increasing progressively by 35 W starting at 100 W for men and at 75 W for women. Gas exchange variables were measured throughout the test using an Oxycon Pro breath-by-breath gas analyzer. Electrocardiography was monitored continuously using a CARDIOVIT CS-200 system during the exercise protocol, as well as during a 10-minute recovery period. The efficiency of energy supply mechanisms for muscle activity was evaluated based on these physical performance metrics. Statistical analysis was performed using Statistica software, version 23.0 (StatSoft Inc., USA).

Results. The developed reference profiles for physically impaired athletes can be applied at all stages of long-term athlete development. Specifically, during the foundational stages of training, low (below the 3rd percentile) and below-average (3rd–10th percentiles) values can be interpreted as average and above average for that developmental cohort. Conversely, at the advanced training stage, average and above-average percentile ranks can be classified as high performance indicators. This shift reflects the progressive training demands, the enhancement of functional capacity, and the transition to elite levels of athletic performance.

Conclusions. The identified model characteristics for key parameters of functional fitness during exercise testing can be used in the scientific-methodological and biomedical support of Paralympic athletes in winter sports. The obtained results complement the database of scientific research aimed at improving the training system for Paralympians with MI in winter sports and enhancing their athletic achievements.

Keywords: Paralympic sport; performance capacity; musculoskeletal impairment, MI; maximal oxygen uptake, $VO_{2\,max}$; aerobic performance; model characteristics; adapted physical activity; cross-country skiing; alpine skiing; ice hockey; anaerobic threshold

For citation: Pastuhova I.V., Kruglova I.V. Model characteristics of functional fitness of Paralympians with musculoskeletal impairments in winter sports. *Extreme Medicine*. 2026. https://doi.org/10.47183/mes.2026-470

Funding. The study was conducted without sponsorship.

Compliance with the ethical principles. Ethical committee approval was not required, as anonymised medical record data (archival materials) of the athletes were analysed. All participants provided voluntary consent for the use of their anonymised medical data in scientific research.

Potential conflict of interest. The authors declare no conflict of interest.

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Received: 3 Mar. 2026 **Revised:** 20 Apr. 2026 **Accepted:** 23 Apr. 2026 **Online first:** 5 Aug. 2026

УДК 612.766.1

МОДЕЛЬНЫЕ ХАРАКТЕРИСТИКИ ФУНКЦИОНАЛЬНОЙ ПОДГОТОВЛЕННОСТИ ПАРАЛИМПИЙЦЕВ С ПОРАЖЕНИЕМ ОПОРНО-ДВИГАТЕЛЬНОГО АППАРАТА В ЗИМНИХ ВИДАХ СПОРТА

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Введение. В рамках государственной программы «Развитие физической культуры и спорта» активно развиваются адаптивная физкультура и паралимпийский спорт. В этих условиях особую значимость приобретает разработка модельных характеристик функциональной подготовленности паралимпийцев с поражением опорно-двигательного аппарата (ПОДА) с целью повышения эффективности тренировочного процесса как на этапе спортивного совершенствования, так и при спортивном отборе.

Цель. Определение модельных характеристик функциональной производительности спортсменов-паралимпийцев зимних видов спорта с ПОДА для реализации спортивной подготовки в период олимпийского цикла до 2030 г.

Материалы и методы. Проведен ретроспективный анализ 1037 протоколов тестирования показателей физической работоспособности 176 спортсменов-паралимпийцев (2015–2025 гг.), выступавших в зимних видах спорта: лыжные гонки «сидя» (LW 5/7–12) и «стоя» (LW 2–5/7), следж-хоккей «сидя» (LW 5/7–12), горные лыжи в категории «стоя» (LW 2–5/7) и керлинг на колясках (LW 5/7–12). Функциональные показатели определяли по нагрузочному тесту согласно протоколу ступенчато-повышающего теста ВНИИФКа для здоровых спортсменов, модифицированного для спортсменов, выполняющих работу руками на ручном эргометре. Для спортсменов-лыжников (категория «стоя») применяли ступенчато-повышающий тест для выполнения предельной мышечной работы «до отказа» на беговом тредбане HP Cosmos (длительность ступени — 3 мин, мощность нагрузки для мужчин и женщин — 100, 150, 200, 250 и далее Вт, угол подъема полотна — 1С); в категории «сидя» — ступенчато-повышающий тест на ручном эргометре с длительностью ступени 3 мин, мощностью нагрузки для мужчин: 40, 60, 80, 100 и далее Вт, для женщин: 20, 40, 60, 80 и далее Вт. Для следж-хоккеистов использовали ступенчато-повышающий тест на ручном эргометре с длительностью ступени 3 мин, мощностью нагрузки для мужчин 40, 60, 80, 100 и далее Вт; для горнолыжников и параснoубордистов — ступенчато-повышающий тест для выполнения предельной мышечной работы «до отказа» на велоэргометре (Schiller, Швейцария) с длительностью ступени 3 мин, мощностью нагрузки для мужчин: 100, 135, 170 и далее Вт, женщин: 75, 100, 135 и далее Вт. Показатели газообмена измеряли на протяжении всего теста газоанализатором Oxycon Pro. Регистрацию ЭКГ проводили при помощи CARDIOVIT CS-200 на протяжении всего теста, а также в течение 10 мин после его окончания. Эффективность механизмов энергообеспечения мышечной деятельности изучали по показателям работоспособности. Статистическая обработка данных проведена с использованием пакета прикладных программ Statistica v. 23.0 (StatSoftInc, США).

Результаты. Полученные модельные характеристики показателей работоспособности спортсменов с ПОДА можно применять на всех этапах многолетней подготовки спортсменов. Так, для начальных этапов спортивной подготовки низкие (до 3 центилей) и ниже среднего (3–10 центилей) значения модельных характеристик могут быть интерпретированы как средние и выше среднего, в то же время на этапах спортивного совершенствования средние центильные уровни и выше среднего могут рассматриваться как высокие. Это связано с постепенным усложнением задач, развитием функциональных возможностей и переходом к более высоким уровням мастерства.

Выводы. Выявленные модельные характеристики для основных показателей функциональной подготовленности при нагрузочном тестировании могут быть использованы в научно-методическом и медико-биологическом сопровождении спортсменов-паралимпийцев в зимних видах спорта. Полученные результаты дополняют базу данных научных исследований, направленных на совершенствование системы подготовки паралимпийцев с ПОДА в зимних видах спорта и повышение их спортивных достижений.

Ключевые слова: паралимпийский спорт; работоспособность; поражение опорно-двигательного аппарата, ПОДА; максимальное потребление кислорода, МПК; аэробная производительность; модельные характеристики; адаптивная физкультура; лыжные гонки; горные лыжи; следж-хоккей; анаэробный порог

Для цитирования: Пастухова И.В., Круглова И.В. Модельные характеристики функциональной подготовленности паралимпийцев с поражением опорно-двигательного аппарата в зимних видах спорта. *Экстремальная биомедицина*. 2026. https://doi.org/10.47183/mes.2026-470

Финансирование. Исследование выполнено без спонсорской поддержки.

Соответствие принципам этики. Одобрение комитетом по этике не требовалось, поскольку были проанализированы обезличенные данные медицинских карт (архивные материалы) спортсменов. Всеми участниками подписано добровольное согласие на использование своих обезличенных медицинских данных в научных исследованиях.

Потенциальный конфликт интересов. Авторы заявляют об отсутствии конфликта интересов.

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Статья поступила: 03.03.2026 **После доработки:** 20.04.2026 **Принята к публикации:** 23.04.2026 **Online first:** 05.08.2026

INTRODUCTION

As part of the implementation of the State Programme "Development of Physical Culture and Sport"[1], an unprecedentedly large-scale efforts are underway to advance adaptive physical education and Paralympic sport. Increasing numbers of children with disabilities and veterans of the special military operation (SMO) who were injured in combat are being engaged in physical culture and sport. As a result of these efforts, a system of long-term athlete development is beginning to take shape. This system, in its form and requirements, is approaching that of Olympic training. It involves the formation and expansion of mechanisms for long-term adaptation to high-intensity specific muscle activity.

Further improvement of competitive outcomes in Paralympic sports becomes impossible without advanced research into all components of performance capacity, as well as scientific and methodological support (SMS) and medical and biological support (MBS) [1].

To substantiate selection criteria/markers within the stages of long-term athlete development, model characteristics of physical fitness gain particular relevance. These include technical, tactical, and psychological parameters, as well as parameters of functional fitness

[1] On the Approval of the State Programme of the Russian Federation "Development of Physical Culture and Sport" and on the Repeal of Certain Acts and Certain Provisions of Certain Acts of the Government of the Russian Federation. http://government.ru/docs/all/136852/

(aerobic and anaerobic performance), taking into account external constraints unrelated to sport [2].

According to Order No. 6 of the Ministry of Sport of the Russian Federation[2], which came into force in 2022, pedagogical standards have been introduced for all Paralympic sports, and specific diagnostic methodologies for sport-specific characteristics are being developed [3, 4].

Specialists from the Saint Petersburg Research Institute of Physical Culture have developed methodological guidelines to assess the functional capacity of athletes with MI in summer Paralympic sports [5]. They have also provided a theoretical substantiation for establishing model characteristics of functional capacity for Paralympic athletes with MI [1].

However, there is insufficient data on the application of physiological performance metrics — such as maximal oxygen uptake (VO_{2max}), oxygen uptake at the anaerobic threshold (AT), heart rate (HR), and power output at the AT along with their maximal values — which are an integral part of an athlete's model characteristics and determine the level of their specific functional fitness. These parameters are integral indicators that allow assessing an athlete's aerobic and anaerobic performance, the improvement of key adaptation mechanisms to high-intensity loads, as well as the tolerance and focus of training loads both within the annual cycle and at the stages of long-term athlete development. Physiological performance metrics also make it possible to study an athlete's functional reserves, and ensure effective management of the training process with subsequent mesocycles.

International research evaluating model characteristics for athletes with MI are typically limited by small sample groups, with a primary focus on disabling pathology and model physiological metrics of athletes competing in the "sitting" category. At the same time, for athletes with MI competing in the "standing" category, performance parameters are often compared with those of elite able-bodied athletes.

The physiological metrics of athletes competing in the "sitting" category (LW 5/7–12) without spinal cord pathology have not been studied, although these athletes represent the most popular and numerous team sports in our country: sledge hockey, wheelchair basketball, sitting volleyball, and others. Some publications note the need for further work on methods for diagnosing physiological metrics in this group of Paralympic athletes [6–8].

In turn, model characteristics imply a body of knowledge not only about specific body composition features, levels of development of general and specific motor abilities, technical-tactical and psychological preparedness, but also about the functional performance of Paralympic athletes that ensures the demonstration of world-class sports results. Pedagogical observations would be incomplete without physiological metrics of performance capacity, which are determined within the framework of biomedical support.

Model characteristics of high-class athletes can be used as criteria for the selection of young athletes and for planning the training process at the stages of initial and in-depth specialised training. This is particularly relevant in the context of developing a system of classical long-term training for Paralympic athletes in Russia [9].

The main areas of comprehensive monitoring in the practice of scientific and methodological support for the sports training of Russian national Paralympic teams include:

- assessment of general and sport-specific athletic conditioning, based on the regulatory requirements of federal sports training standards and specialized exercises designed to fully reveal the competitive potential of a Paralympic athlete;
- analysis of training volume implementation: athletes' training diaries are examined, followed by comparison with training programmes; interviews and questionnaires of coaching staff are also conducted;
- analysis of technical preparedness through digital video recording;
- assessment of physical performance capacity and cardiovascular status. The results of this assessment allow forming a conclusion about the athlete's adaptive capabilities and identifying their reserves;
- psychophysiological testing [9].

Taking into account the application of comprehensive monitoring areas in the sports training system makes it possible to clarify the specific features of model characteristics in Paralympic sports[3]. Thus, determining the model characteristics of physical performance capacity in athletes with MI in winter sports is a relevant research direction.

The study purpose is to determine the model characteristics of functional fitness in Paralympic winter sport athletes with MI and to develop practical recommendations for sports training for the current and next Olympic training cycle up to 2030.

The research objectives are as follows:

1. to categorize the study participants into distinct groups based on their disciplines;
2. to classify athlete cohorts according to the type of functional impairments, based on the applicable sports-medical classification for the selected sports;
3. to perform statistical analysis of the acquired data using SPSS Statistica 23 software to evaluate the normality of their distribution. Based on the results, parameters of various components of athletes' functional capacity will be evaluated using either the standard deviation (sigma) method or percentile rank profiles

[2] Order of the Ministry of Sport of Russia dated 11.01.2022 No. 6 (as amended on 15.07.2025) "On the Approval of the Unified All-Russian Sports Classification (sports not included in the programmes of the Olympic Games, Winter Olympic Games, and not being military-applied or service-applied sports)" (Appendix 62).

[3] Bondarevskiy EYa. Methodology of establishing adequate norms of physical fitness: methodological recommendations. Moscow: VNIIFK; 1983.

relative to the sample mean/median. The results will be evaluated across five performances: low, below average, average, above average, and high.

MATERIALS AND METHODS

The study was conducted at the Sports Medicine Department of the National Center for Sports Medicine of the Federal Medical and Biological Agency. A retrospective analysis was performed on testing protocols for 176 leading Russian Paralympic athletes — members of the national team in cross-country skiing and sledge hockey (151 men and 25 women) — covering the period 2015–2025. A total of 1037 testing sessions were processed.

Winter sports involving athletes with MI are represented by:

- cross-country skiing in the “sitting” category (LW 5/7–12) and the “standing” category (LW 2–5/7);
- sledge hockey in the “sitting” category (LW 5/7–12);
- alpine skiing in the “standing” category (LW 2–5/7);
- wheelchair curling (LW 5/7–12)[4].

Functional parameters were determined using an incremental exercise test protocol originally designed by the VNIIFK for able-bodied athletes[5]. This protocol was adapted for athletes performing upper-body work on an hand ergometer allowing for long-term monitoring of general performance and aerobic capacity parameters in homogeneous groups of athletes who train according to a unified training calendar plan under identical conditions.

For athletes competing in the “standing” category (LW 2–5/7) in cross-country skiing, a stepwise-increasing test was used to perform maximum muscle work until “exhaustion” on a HP Cosmos treadmill. The stage duration was 3 min (to achieve stabilisation of regulated parameters). The load power was set at 100, 150, 200, 250 W and above for both men and women, with the treadmill belt speed set at 9.0, 10.2, 12.8, 14.4 km/h and above, respectively, for each stage. The treadmill incline was 1°. For sitting-position cross-country skiers (category LW 5/7–12), a stepwise-increasing test was performed on an arm ergometer, with a stage duration of 3 min (to achieve stabilisation of regulated parameters). Load power was set as follows: for men — 40, 60, 80, 100 W and above; for women — 20, 40, 60, 80 W and above.

For sledge hockey players (LW 5/7–12), a stepwise-increasing test was used on an arm ergometer, with a stage duration of 3 min (to achieve stabilisation of recorded parameters). The load power for men was set at 40, 60, 80, 100 W and above [10].

For alpine skiers and para-snowboarders (until 2020), a stepwise-increasing test was used to perform maximum muscle work until “exhaustion” on a cycle ergometer (Schiller, Switzerland), with a stage duration of 3 min (to achieve stabilisation of recorded parameters). The load power was set as follows: for men — 100, 135, 170 W and above; for women — 75, 100, 135 W and above (Table 1).

Gas exchange variables were measured continuously throughout the test using an Oxycon Pro breath-by-breath gas analyzer (ERICH JAEGER GmbH, Germany) and terminated after the athlete refused to continue the exercise. ECG recordings were performed using the CARDIOVIT CS-200 diagnostic workstation (Schiller, Switzerland) throughout the test, as well as for 10 min after its completion, to assess the current state of the cardiovascular system and functional changes in the cardiac muscle under conditions of maximum muscle load and during the recovery period. The anaerobic threshold (AnT) was determined based on the dynamics of pulmonary ventilation and the ratio of ventilatory equivalents for CO_2 elimination and O_2 uptake (RER = 1.0). The following parameters, characterising the efficiency of energy supply mechanisms for muscle activity, were analyzed:

- N_{max} — peak power output achieved during the test, W;
- VO_{2max} — maximal oxygen consumption, representing maximal aerobic capacity, mL/min/kg;
- HR_{max} — maximal heart rate at the point of exercise termination (exhaustion), bpm;
- Pwr_{AT} — power output at the anaerobic threshold, W;
- VO_{2AT} — oxygen consumption at the anaerobic threshold, mL/min/kg;
- HR_{AT} — heart rate at the anaerobic threshold, bpm;
- VO_{2AT} / VO_{2max} — percentage ratio of oxygen consumption at the anaerobic threshold relative to the maximal oxygen consumption in the test;
- VE_{max} — maximum minute ventilation, L/min[6].

All listed parameters were selected to determine model characteristics.

Model characteristics of performance parameters were determined according to classification cohorts (Table 2).

Due to the limited sample size of female athletes from national teams, gender-specific model characteristics (Table 2). Separating them into a separate group would have been statistically unreliable, so their performance parameters were combined with those of the men. When interpreting the load test, if women’s results were “above average”, they were considered “high”.

Statistical data processing was performed using the Statistica software package, version 23.0 (StatSoft Inc., USA). Since the studied quantitative parameters had a non-normal distribution (as confirmed by the Kolmogorov–Smirnov and Shapiro–Wilk tests), the

[4] Idrisova GZ. (Author-Compiler). Classification of athletes in Paralympic sports. Moscow: Russian Paralympic Committee; 2020.

[5] Order of the Ministry of Sport and Tourism of the Russian Federation dated 15.03.2011 No. 197 “On Approval of the Main Types and Requirements for the Content of Programmes for Scientific and Methodological Support of Russian National Sports Teams”.

[6] Pastukhova IV. Individual Heart Rate Training Zones for the Preparation of Paralympic Athletes with Musculoskeletal Disorders in Winter Sports. Extended abstract of the dissertation for the degree of Candidate of Medical Sciences. Moscow; 2016.

Table 1. Exercise testing protocols for winter MI athletes: aligned with sports and functional Paralympic classifications

Sports medical classification \ Olympic sports classification	Cyclic sports (cross-country skiing)	Speed-strength and game sports (alpine skiing, para-snowboarding, sledge hockey)
Lower extremity impairment, spinal cord injury at all levels (LW 5/7–12)	**Hand ergometry** **Protocol:** stepwise-increasing test on an arm ergometer until "exhaustion", with a stage duration of 3 min (to achieve stabilisation of recorded parameters). The load power was set as follows: for men — 40, 60, 80, 100 W and above; for women — 20, 40, 60, 80 W and above	**Hand ergometry** **Protocol:** stepwise-increasing test on an arm ergometer until "exhaustion", with a stage duration of 3 min (to achieve stabilisation of recorded parameters). The load power was set as follows: for men — 40, 60, 80, 100 W and above; for women — 20, 40, 60, 80 W and above
Upper limb impairment (2–5/7)	**Treadmill test** **Protocol:** stepwise-increasing test on a HP Cosmos treadmill to perform maximum muscle work until "exhaustion", with a stage duration of 3 min (to achieve stabilisation of recorded parameters). The load power was set at 100, 150, 200, 250 W and above for both men and women, corresponding to the belt speed of 9.0, 10.2, 12.8, 14.4 km/h and above per stage, respectively. The treadmill incline was set at 1°	**Cycle ergometry** **Protocol:** stepwise-increasing test on a cycle ergometer (Schiller, Switzerland) until "exhaustion" to perform maximum muscle work, with a stage duration of 3 min (to achieve stabilisation of recorded parameters). The load power was set as follows: for men — 100, 135, 170 W and above; for women — 75, 100, 135 W and above

Table prepared by the authors

percentile table method was applied. This method is based on non-parametric statistical analysis and is not constrained by the distribution pattern of the parameters [11, 12]. To interpret the obtained results, the following stratification of percentile ranges was adopted [13]:

- below the 3rd percentile — the range of very low values; such indicators are observed in athletes of the studied groups in 3% of cases. These values may be considered normal for athletes in their 1st or 2nd year of training and serve as a starting point for further athletic development;
- 3rd–10th percentile — the range of low values, observed in winter sports athletes with MI in 7% of cases. They may be interpreted as good and high for athletes in their second to third year of training, during the preliminary basic training phase (2–3 years of training);
- 10th–25th percentile — the "below average" range, observed in athletes in the selected sports in 15% of cases. These values may be classified as good and high in the third to 4th year of training, when transitioning to the special basic training period;
- 25th–75th percentile — the average range, observed in winter sports athletes with MI in 50% of cases. These values are regarded as good and high during the special basic period and when transitioning to the phase of preparation for top achievements (after 4–5 years of training);
- 75th–90th percentile — the "above average" range, recorded in athletes with MI in the selected sports in 15% of cases. They may be interpreted as high during the phase of athletic improvement, which typically lasts 2 years;
- 90th–97th percentile — the high range, noted in winter sports athletes with MI in 7% of cases. These values are assessed as high during the phase of athletic improvement and when transitioning to the phase of top athletic achievements;
- from the 97th percentile onwards — the range of very high values, observed in outstanding athletes in cyclic sports in no more than 3% of cases; this corresponds to the phase of top athletic achievements.

RESULTS AND DISCUSSION

Based on the obtained data, reference performance profiles were established for both prospective and active athletes.

For sitting cross-country skiing athletes (LW 5/7–12), the core functional capacity components derived from

Table 2. Characteristic of the studied cohorts

<table>
<tr><th rowspan="2">Sports types, functional classes[7]</th><th rowspan="2">Athletes' age, M ± m</th><th colspan="2">Number of athletes, n (%)</th><th rowspan="2">Number of studies</th><th rowspan="2">Qualification</th></tr>
<tr><th>Males</th><th>Females</th></tr>
<tr><td rowspan="5">Sitting cross-country skiing (LW 5/7–12)</td><td rowspan="5">31.2 ± 8.08</td><td colspan="2">35</td><td rowspan="5">194</td><td>ZMS — 12 (34.2%)</td></tr>
<tr><td rowspan="4">25 (71.4%)</td><td rowspan="4">10 (28.5%)</td><td>MSMK — 9 (25.7%)</td></tr>
<tr><td>MS — 10 (28.5%)</td></tr>
<tr><td>CMS — 3 (8.6%)</td></tr>
<tr><td>Adult 1st-rank athlete — 1 (2.9%)</td></tr>
<tr><td rowspan="4">Standing cross-country skiing (LW 2–5/7), including visually impaired athletes (B1, B2)</td><td rowspan="4">24.3 ± 7.09</td><td colspan="2">31</td><td rowspan="4">177</td><td>ZMS — 10 (32.3%)</td></tr>
<tr><td rowspan="3">21 (67.7%)</td><td rowspan="3">10 (32.3%)</td><td>MSMK — 4 (12.9%)</td></tr>
<tr><td>MS — 2 (6.4%)</td></tr>
<tr><td>CMS — 15 (43.2%)</td></tr>
<tr><td rowspan="5">Alpine skiing and para-snowboarding* (SB — LL1, SB — LL2, SB — UL)</td><td rowspan="5">25 ± 7.1</td><td colspan="2" rowspan="2">29</td><td rowspan="5">166</td><td>ZMS — 6 (20.6%)</td></tr>
<tr><td>MSMK — 6 (20.6%)</td></tr>
<tr><td rowspan="3">24 (82.2%)</td><td rowspan="3">5 (17.2%)</td><td>MS — 3 (10.3%)</td></tr>
<tr><td>CMS — 11 (37.9%)</td></tr>
<tr><td>Adult 1st-rank athlete — 3 (10.3%)</td></tr>
<tr><td rowspan="4">Sledge hockey (LW 5/7–12)</td><td rowspan="4">30.2 ± 6.1</td><td colspan="2">81</td><td rowspan="4">500</td><td>ZMS — 9 (11.1%)</td></tr>
<tr><td rowspan="3">81 (100%)</td><td rowspan="3">no</td><td>MSMK — 19 (23.5%)</td></tr>
<tr><td>MS — 18 (22.2%)</td></tr>
<tr><td>CMS — 35 (43.2%)</td></tr>
</table>

Table prepared by the authors based on their own data

Note. ZMS — Honored Master of Sports; MSMK — International-Class Master of Sports; MS — Master of Sports; CMS — Candidate Master of Sports; * — the study group included athletes with musculoskeletal impairments (MI) and visual impairments: until 2018, the functional classes of athletes in this sport were designated as (LW 2–5/7, B2, B3). Athletes with these impairments trained in the same group according to the same Unified Calendar Plan (ECP). The functional capability requirements, according to the classification, are similar — therefore, we considered them as a single group.

the incremental exercise testing were stratified into distinct performance levels, as presented in Table 3.

When assessing heart rate (HR) responses to exercise (HR at VO_{2max}), specifically in cyclic disciplines, it is important to keep in mind that HR values tend to decrease as fitness improves. However, proof that the test was performed at maximum power is the peak HR, which should be 180 bpm or higher. This marker is only reliable when assessing elite athletes and those in the advanced stages of athletic development who are over 18 years of age. Movement economy parameters are evaluated in inverse proportion: the higher the value, the lower the efficiency.

Cross-country skiers competing in the "standing" category (LW 2–5/7) who performed a treadmill exercise test showed values close to those of healthy athletes (Table 4).

Based on the results of exercise testing of alpine skiers and para-snowboarders with MI, the model characteristics of functional state components were distributed as follows (Table 5).

The model characteristics of the largest group of sledge hockey players are presented in Table 6.

Model characteristics of performance parameters reflect the patterns of the athlete training process, enable forecasting of sports results and structuring of the training regimen, and also provide a foundation for developing and implementing new athlete training technologies in practice. The model characteristics of performance parameters for athletes with MI

[7] Idrisova GZ. Classification of Athletes in Paralympic Sports. Moscow: Russian Paralympic Committee; 2020.

Table 3. Model characteristics of performance parameters for cross-country skiers competing in the “sitting” category (LW 5/7–12)

Parameter	Percentiles						
	Very low	Low	Below average	Average	Above average	High	Very high
Pwr_{AT}, W	<31	31–37	37–48	48–92	92–115	115–138	>138
% T_{AerT}, %	<7.5	7.5–12.3	12.3–27.2	27.2–71.6	71.6–87.3	87.3–95.3	>95.3
VO_{2AT}, mL O_2/min/kg	<12.4	12.4–16.2	16.2–19.6	19.6–31.48	31.48–35.14	35.14–38.6	>38.6
HR_{AT}, bpm	<90	90–102	102–123	123–156	156–170	170–179	>179
VO_{2max}, mL/min/kg	<23.6	23.6–27.5	27.5–30.9	30.9–41.1	41.1–45.6	45.6–49.7	>49.7
Pwr VO_{2max}, W	<63	63–77	77–92	92–135	135–158	158–189	>189
HR VO_{2max}, bpm	<148	148–155	155–163	163–183	183–189	189–198	>198
% AT/VO_{2max}, %	<37.2	37.2–42.6	42.6–56.3	56.3–82.9	82.9–92.0	92.0–98.2	>98.2
VE_{max}, L/min	<42.3	42.3–49.3	49.3–57.1	57.1–91.8	91.8–108.5	108.5–144	>144

Table prepared by the authors based on their own data

Note. Pwr_{AT} — anaerobic threshold power; T_{AerT} — exercise time at the aerobic threshold; VO_{2AT} — oxygen uptake at the anaerobic threshold; HR_{AT} — heart rate at the anaerobic threshold; VO_{2max} — maximal oxygen uptake; Pwr VO_{2max} — power output at maximal oxygen uptake; HR VO_{2max} — heart rate at maximal oxygen uptake; % AT/VO_{2max} — percentage ratio of anaerobic threshold to maximal oxygen uptake; VE_{max} — maximal minute ventilation.

Table 4. Performance model characteristics for standing-category cross-country skiers (LW 2–5/7)

Parameter	Percentiles						
	Very low	Low	Below average	Average	Above average	High	Very high
S_{AT}, W	<9.0	9.0–11.8	11.8–12.2	12.2–16.2	16.2–18.5	18.5–19.3	>19.3
% T_{AerT}, %	<20.0	20.0–44.2	44.2–62.2	62.2–87.9	87.9–93.3	93.3–97.6	>97.6
VO_{2AT}, mL O_2/min/kg	<33.63	33.63–37.6	37.6–42.3	42.3–55.7	55.7–61.9	61.9–66.9	>66.9
HR_{AT}, bpm	<135	135–155	155–166	166–185	185–191	191–197	>197
VO_{2max}, mL/min/kg	<41.1	41.1–43.8	43.8–47.7	47.7–62.9	62.9–68.1	68.1–71.5	>71.5
Pwr VO_{2max}, W	<11.0	11.0–12.4	12.4–14.6	14.6–17.4	17.4–19.2	19.2–21.8	>21.8
HR VO_{2max}, bpm	<163	163–169	169–180	180–194	194–199	199–202	>202
% AT/VO_{2max}, %	<69.2	69.2–75.8	75.8–82.6	82.6–94.9	94.9–97.8	97.8–98.9	>98.9
VE_{max}, L/min	<74.7	74.7–83.7	83.7–103.4	103.4–137	137–151.6	151.6–168	>168

Table prepared by the authors based on their own data

Note. S_{AT} — anaerobic threshold speed; T_{AerT} — exercise time at the aerobic threshold; VO_{2AT} — oxygen uptake at the anaerobic threshold; HR_{AT} — heart rate at the anaerobic threshold; VO_{2max} — maximal oxygen uptake; S VO_{2max} — speed at maximal oxygen uptake; HR VO_{2max} — heart rate at maximal oxygen uptake; % AT/VO_{2max} — percentage ratio of anaerobic threshold to maximal oxygen uptake; VE_{max} — maximal minute ventilation.

obtained in our study can be applied at all stages of their long-term training. For instance, at the initial stages of sports training, low (below 3rd centile) and below-average (3rd–10th centile) values of model characteristics may be interpreted as average and above-average. Meanwhile, at the stages of athletic advancement, average centile levels and above-average values may be considered high. This is due to the gradual increase in task complexity, development of functional capabilities, and transition to higher levels of mastery. Applying the obtained parameters will allow effective management of sports training for

Table 5. Performance model characteristics for standing-category alpine skiers with musculoskeletal and visual impairments (B1, B2)

Parameter	Percentiles						
	Very low	Low	Below average	Average	Above average	High	Very high
Pwr_{AT}, W	<14	14–51	51–110	110–184	184–212	212–234	>234
% T_{AerT}, %	<17	17–22.9	22.9–32.9	32.9–69.8	69.8–82.2	82.2–91.3	>91.3
VO_{2AT}, mL O_2/min/kg	<18.6	18.6–22.2	22.2–25.3	25.3–35.3	35.3–40.1	40.1–43.0	>43.0
HR_{AT}, bpm	<122	122–131	131–144	144–164	164–173	173–179	>179
VO_{2max}, mL/min/kg	<28.2	28.2–31. 7	31.7–36.4	36.4–44.6	44.6–47.4	47.4–52.3	>52.3
Pwr VO_{2max}, W	<123	123–150	150–173	173–247	247–272	272–298	>298
HR VO_{2max}, bpm	<153	153–166	166–172	172–187	187–190	190–194	>194
% AT/VO_{2max}, %	<47.2	47.2–56.8	56.8–65.8	65.8–84.6	84.6–94.3	94.3–95.6	>95.6
VE_{max}, L/min		For speed-strength sports in the group of athletes with musculoskeletal and visual disabilities, this parameter was not assessed due to its low informational value.					

Table prepared by the authors based on their own data

Note. Pwr_{AT} — anaerobic threshold power; T_{AerT} — exercise time at the aerobic threshold; VO_{2AT} — oxygen uptake at the anaerobic threshold; HR_{AT} — heart rate at the anaerobic threshold; VO_{2max} — maximal oxygen uptake; Pwr VO_{2max} — power output at maximal oxygen uptake; HR VO_{2max} — heart rate at maximal oxygen uptake; % AT/VO_{2max} — percentage ratio of anaerobic threshold to maximal oxygen uptake; VE_{max} — maximal minute ventilation.

Table 6. Performance model characteristics for sitting-category sledge hockey athletes (LW 5/7–12)

Parameter	Percentiles						
	Very low	Low	Below average	Average	Above average	High	Very high
Pwr_{AT}, W	<20	20–37	37–57	57–103	103–121	121–139	>139
% T_{AerT}, %	<4.3	4.3–12.5	12.5–25.3	25.3–75.3	75.3–91.5	91.5–97.5	>97.5
VO_{2AT}, mL O_2/min/kg	<10.7	10.7–14.5	14.5–18.3	18.3–29.5	29.5–34.1	34.1–40.2	>40.2
HR_{AT}, bpm	<92	92–106	106–120	120–156	156–169	169–181	>181
VO_{2max}, mL/min/kg	<22.8	22.8–26.0	26.0–29.8	29.8–38.9	38.9–41.3	41.3–44.8	>44.8
Pwr VO_{2max}, W	<71	71–89	89–108	108–141	141–153	153–163	>163
HR VO_{2max}, bpm	<141	141–152	152–160	160–179	179–186	186–195	>195
% AT/VO_{2max}, %	<38.6	38.6–45.5	45.5–57.1	57.1–87.2	87.2–96.5	96.5–98.0	>98.0
VE_{max}, L/min	<56.0	56.0–63.1	63.1–75.0	75.0–102.5	102.5–115.0	115–129.6	>129.6

Table prepared by the authors based on their own data

Note. Pwr_{AT} — anaerobic threshold power; T_{AerT} — exercise time at the aerobic threshold; VO_{2AT} — oxygen uptake at the anaerobic threshold; HR_{AT} — heart rate at the anaerobic threshold; VO_{2max} — maximal oxygen uptake; Pwr VO_{2max} — power output at maximal oxygen uptake; HR VO_{2max} — heart rate at maximal oxygen uptake; % AT/VO_{2max} — percentage ratio of anaerobic threshold to maximal oxygen uptake; VE_{max} — maximal minute ventilation.

athletes with different training process specifics in a given sport.

The historical continuity, recognized by the authors as justified, suggests that when addressing the functional capabilities of athletes with MI, it is essential to distance oneself as much as possible from nosological units. In the absence of complications, such units do not serve as grounds for disqualifying an athlete from competitions or training sessions. In athlete classification, the primary consideration is to maximize the equalization of their functional capabilities when performing locomotor actions in the chosen sport.

However, in wheelchair curling and partially in sitting cross-country skiing, it is impossible to completely disregard nosological impairments when assessing athletes' functional capabilities. This is because some of these impairments directly affect performance indicators, as the majority of athletes have previously sustained a spinal cord injury. Depending on the level of spinal cord damage, the injury results in lower paraplegia or tetraplegia. Other causes of disability in this group of athletes include poliomyelitis and post-polio syndrome, developmental disorders, leg amputations, as well as neuromuscular diseases and musculoskeletal disorders [14, 15].

In accordance with the Olympic classification, wheelchair curling is categorized as a precision sport. According to Order No. 1144n of the Ministry of Health of the Russian Federation dated 23.10.2020, exercise testing on a hand ergometer is conducted using the PWC170 protocol. The purpose of this protocol for this category of athletes is to identify the cardiovascular system's response to submaximal load, as assessing performance indicators is often not feasible. The HR during the second load rarely exceeds 30 bpm in such pathology, which makes calculating VO_{2max} using the Karpman formula unreliable [16]. Moreover, overall performance indicators in applied sports are of secondary importance and do not determine the achievement of high sports results. Therefore, this athlete cohort was not considered in this study. In the process of selecting athletes for the next stages of long-term training, we recommend using pedagogical model characteristics [5].

The most challenging category of Paralympic athletes comprises those with spinal cord injuries. These athletes exhibit significant physiological differences in the development of physical capabilities compared to able-bodied athletes. Moreover, these differences are heterogeneous and depend on the level of spinal cord damage. For instance, there is a notable difference in maximal oxygen uptake (VO_{2max}) between able-bodied athletes and athletes with disabilities. VO_{2max} is an integral indicator reflecting an athlete's endurance and overall physical performance based on the power of the aerobic energy supply mechanism for sport-specific muscle activity. It depends on both oxygen delivery to tissues (primarily skeletal muscles) and their oxygen consumption. In addition, athletes with spinal cord injuries have: a cardiac output that is 10–25% lower, and a stroke volume that is 15–30% lower than able-bodied athletes.

In cases of cervical spine injury above the level where the sympathetic trunks originate, tetraplegia and arterial hypotension are frequently observed, along with low maximum HR and reduced venous return due to venous blood stasis. This further decreases cardiac output and stroke volume, consequently leading to reduced oxygen supply to the tissues. Therefore, conventional hemodynamic parameters — such as HR and blood pressure (BP) — cannot be used as markers of physical performance level during exercise testing in athletes with MI.

Compared to able-bodied athletes, Paralympic athletes with spinal cord injuries exhibit lower muscle mass. For instance, in cases of tetraplegia, it is typically lower than in lower paraplegia. When muscle atrophy occurs, VO_{2max} also decreases. In athletes with paraplegia, the VO_{2max} value is on average similar to that of sedentary individuals, while in athletes with tetraplegia it is even lower.

The presented data account for the low tolerance of upper limb muscles to physical loads, as a consequence of inadequate blood supply, hypokinetic circulation, and limited aerobic energy capacity. Under load, the transition to anaerobic metabolism is reached significantly faster.

Individuals with spinal cord injuries experience the influence of several specific factors during physical training and exercise. These challenges are caused by damage to the central nervous system and manifest as motor, sensory, and autonomic dysfunction. Such specific risk factors include:

- unstable trunk position;
- hypotensive response to exercise;
- orthostatic hypotension;
- autonomic dysreflexia;
- muscle spasms;
- impaired thermoregulation [17].

CONCLUSION

The results of the study can be used by sports medicine physicians to assess the functional capacity of the examined athletes, provided that exercise testing is conducted according to the protocols specified in the article. The theoretical significance of the work lies in expanding the understanding of physiological ranges of performance capacity among athletes of varying fitness levels. These findings can be widely applied both in MBS and in scientific and SMS for high-performance sports. Furthermore, these findings can be used for athlete selection (especially for adults) for participation in winter sports, with the aim of determining the stages of their long-term training. This is particularly relevant for participants of SMO who have retained their athletic physical condition after an injury and subsequent rehabilitation. The obtained results may be equally relevant for children with disabilities who are beginning to train in winter sports within adaptive sports sections and adaptive physical education programmes. The parameters obtained through hand ergometry hold significant practical value for athlete selection and training in high-performance sports.

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Authors' contribution. All authors confirm that their authorship meets the ICMJE criteria. The primary contributions are distributed as follows: Inna V. Pastuhova — data analysis, study organization, database development and management, study conception and design; Irina V. Kruglova — database compilation, study organization, manuscript drafting and editing.

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