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IMPACT OF ICE-WATER SWIMS ON CARDIAC CONDUCTION AND AUTONOMIC REGULATION IN WINTER SWIMMERS

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Introduction. As a kind of sport, winter swimming differs from pool- or open-water swimming due to the extreme cold stress it places on the body. Swims in cold water with facial immersion trigger a diving reflex, which may be accompanied by the development of cardiac arrhythmias under low-temperature conditions. We believe that specific criteria should be developed for permitting individuals to engage in cold-water swimming.
Objective. Study of the characteristics of changes in the state of the cardiovascular and nervous systems, autonomic regulation, and metabolic parameters in winter swimmers at water temperatures from +0.5 °C to +2.0 °C both over various standard distances and during a 10-min swim of 450–550 m.
Materials and methods. Under competitive conditions and during training camps (at water temperatures from +0.5 °C to +1.5 °C and air temperatures from –15 °C to –18 °C), 24 winter swimmers were examined. These were 9 women aged 23–55 (mean age 39.1 ± 2.7 years); 3 men aged 71 ± 3 years; and 12 men aged 35–60 (mean age 43 ± 1.8 years), all of whom had received medical clearance for participation. The participants' condition was analyzed before and after swims at distances of 25 m backstroke, 25 m and 200 m front crawl (freestyle), as well as after a 10-min swim of 400–450 m. The functional state of the body was assessed using 12-lead electrocardiography, blood pressure measurement, determination of capillary blood glucose concentration, and assessment of simple sensorimotor reaction to a light stimulus. Statistical analysis to identify differences between parameters was performed using the GraphPad Prism 8 software package for Windows 10.
Results. A statistically significant increase in the mean capillary blood glucose levels was observed after swims of 25 m ($p < 0.05$), 200 m ($p < 0.01$), and 400 m compared to the baseline. An increase in the simple sensorimotor reaction time after 10-min swims was noted; thus, the baseline of 263 ± 10 ms vs. 328 ± 21 ms after the swim ($p < 0.01$). According to ECG data, at baseline, 67% of the examined individuals showed a widened P wave > 0.11 ms. After short-distance swims of 25 m, P wave duration exceeded the upper limit of normal in 85% of the examined. Compared to backstroke swims, swims with facial immersion in water were accompanied by a significantly more pronounced widening of the P wave ($p < 0.05$), slowing of atrial conduction PQ ($p < 0.01$), and a more pronounced increase in the QTc interval ($p < 0.05$). The QTc value progressively increased in accordance with the duration of the swims. During a 10-min swim, 50% of the examined individuals showed a QTc > 500 ms.
Conclusions. Low water temperature is a factor that, even in cold-adapted athletes, provokes stress accompanied by an increase in blood glucose. During swims in cold water with facial immersion, the activated diving reflex triggers cardiac arrhythmias. During long-distance swims, conduction in the nervous system slows down, manifested in an increased simple sensorimotor reaction time and slowed myocardial conduction, reaching pathological values. In this regard, we believe that an additional criterion for medical clearance — assessment of the response of the cardiovascular system to cold-water immersion — should be developed and implemented for beginners wishing to engage in cold-water swimming, in order to avoid the risk of a pathological cardiovascular reaction.

Keywords: cold-water swimming; nervous system; cardiovascular system; autonomic regulation; cardiac arrhythmias; intracardiac conduction; hypertensive response; sensorimotor reaction; cold-water immersion

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ВЛИЯНИЕ ЗАПЛЫВОВ В ЛЕДЯНОЙ ВОДЕ НА ПРОВОДЯЩУЮ СИСТЕМУ СЕРДЦА И ВЕГЕТАТИВНУЮ РЕГУЛЯЦИЮ У ПЛОВЦОВ ЗИМНЕГО ПЛАВАНИЯ

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Введение. Зимнее плавание как вид спорта отличается от классического плавания и плавания в открытой воде экстремальной холодовой нагрузкой на организм. При заплывах в холодной воде с погружением лица в воду реализуется нырятельная реакция, которая в условиях низких температур может сопровождаться формированием сердечных аритмий. Мы полагаем, что для допуска к занятиям холодовым плаванием необходима разработка специальных критериев.
Цель. Изучение особенностей изменений состояния сердечно-сосудистой, нервной систем, вегетативной регуляции и метаболических показателей у пловцов зимнего плавания при температуре воды от +0,5 до +2,0 °С на различных дистанциях и 10-минутном заплыве на 450–550 м.
Материалы и методы. В условиях соревновательной деятельности и учебно-тренировочных сборов (при температуре воды от +0,5 до +1,5 °С, температуре воздуха от -15 до -18 °С) проведено обследование 24 спортсменов зимнего плавания: 9 женщин (23–55 лет; средний возраст 39,1 ± 2,7 года); 3 мужчин в возрасте 71 ± 3 года; 12 мужчин (35–60 лет; средний возраст 43,0 ± 1,8 года), имевших медицинский допуск к занятиям. Состояние испытуемых анализировали до и после заплывов на дистанциях 25 м кролем на спине, 25 и 200 м вольным стилем на груди и после 10-минутного заплыва на 400–450 м. Для оценки функционального состояния проведены: электрокардиография в 12 отведениях, измерение артериального давления, определение концентрации глюкозы в капиллярной крови, определение простой сенсомоторной реакции на световой раздражитель. Статистический анализ для выявления различий между показателями выполнен с использованием пакета программного обеспечения GraphPad Prism 8 для Windows 10.
Результаты. Установлено статистически значимое повышение среднегрупповых показателей уровня глюкозы в капиллярной крови после заплывов на 25 м ($p < 0,05$), 200 м ($p < 0,01$) и 400 м относительно исходного состояния; увеличение времени простой сенсомоторной реакции после 10-минутных заплывов: в исходном состоянии 263 ± 10 и 328 ± 21 мс после заплыва ($p < 0,01$). По данным ЭКГ в исходном состоянии у 67% обследованных выявлено уширение зубца Р > 0,11 мс. После заплывов на короткие дистанции 25 м длительность зубца Р выходит за верхний предел нормы у 85% обследованных. По сравнению с заплывами на спине заплывы с погружением лица в воду сопровождались достоверно более выраженным уширением зубца Р ($p < 0,05$), замедлением проведения через предсердия — PQ ($p < 0,01$), более выраженным увеличением QTc показателя ($p < 0,05$). Величина QTc прогрессирующе увеличивается в соответствии с длительностью заплывов. При 10-минутном заплыве у 50% обследованных QTc > 500 мс.
Выводы. Низкая температура воды — фактор, который даже у адаптированных к холоду спортсменов провоцирует стресс, сопровождающийся повышением глюкозы в крови. При заплывах с погружением лица в воду реализуется нырятельный рефлекс, который в холодной воде может провоцировать сердечные аритмии. При заплывах на длинные дистанции происходит замедление проведения в нервной системе, что отражается в увеличении времени простой сенсомоторной реакции и замедлении проводимости миокарда, достигающего патологического значения. В связи с этим считаем, что для новичков, желающих заниматься холодовым плаванием, во избежание риска патологического ответа сердечно-сосудистой системы необходима разработка и введение в практику допуска дополнительного критерия — оценки реакции сердечно-сосудистой системы на водно-холодовую иммерсию.

Ключевые слова: холодовое плавание; нервная система; сердечно-сосудистая система; автономная регуляция; сердечные аритмии; внутрисердечное проведение; гипертензивный ответ; сенсомоторная реакция; водно-холодовая иммерсия

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Соответствие принципам этики: исследование проведено в соответствии с Хельсинкской декларацией и одобрено Этическим комитетом Санкт-Петербургского государственного университета (протокол № 40 от 07.03.2012). Все испытуемые предварительно были ознакомлены с протоколом обследования, подписали согласие об участии в нем и дали разрешение на публикацию обезличенных данных.

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INTRODUCTION

Today, cold-water (also referred to as winter or ice) swimming has gained popularity worldwide. In 2022, winter swimming was included in the All-Russian Register of Sports in the Russian Federation.[1] Despite a relatively well-developed system of amateur winter swimming, there is a lack of systematic scientific research in the field of training winter swimming athletes. Therefore, qualified scientific research is required to address various related problems in this field. Among the most important of these are the categorization of competition distances and determining their sequence during competitions. The classification of winter swimming competition categories used in the Russian Federation is based on the categories proposed by the International Winter Swimming Association (IWSA),[2] where category "A" (ice water) with a water temperature from 0°C to +2°C is intended for distances of 25/50/100/200 m; category "B" (freezing water) with a water temperature from +2.1°C to +5°C — for distances of 25/50/100/200/400 m; category "C" (cold water) with a water temperature from +5.1°C to +9°C — for distances of 25/50/100/200/400/500/1000 m.

During competitions in cold water, several extreme factors act on the athlete's body. First, competitive stress is accompanied by activation of the sympathoadrenal system [1], mobilizing the body's functional reserves. Second, the exposure to cold water triggers a set of protective compensatory reactions against hypothermia, such as reflex constriction of peripheral vessels, redistributing blood toward internal organs (the "core"), and activation of heat production responses (shivering and non-shivering thermogenesis). Third, immersion in cold water with the head triggers a set of cardiovascular reactions, referred to as the diving reflex, consisting in the following effects. Under the influence of adrenergic effects, sharp vasoconstriction of peripheral vessels occurs. Simultaneously, the increased cholinergic influence on the myocardium leads to a reflex slowing of the heart rate. At the same time, stimulation of the respiratory tract causes reflex apnea and bronchiolar constriction; as a result, vessels in the pulmonary artery, cerebral, and coronary circulation dilate, redistributing blood toward these areas [1, 2].

Simultaneous activation of parasympathetic (diving reflex) and sympathetic (cold stress, competitive conditions) effects on the heart can lead to the so-called "autonomic conflict," which, during water immersion at low temperatures, may result in the formation of arrhythmias, including those of a fatal nature [3]. It should also be noted that physical and cold-related loads stimulate an increase in oxidative processes followed by ATP production and heat release, which is intended to maintain body temperature. Inclusively, all this raises the load on the body's gas transport systems and, above all, on the cardiovascular system. However, even a slight drop in body temperature in an aggressively cold environment by fractions of a degree can disrupt nervous system functions and slow intracardiac conduction, while a powerful peripheral vasospasm can lead to increased blood pressure.

In this work, we aim to study the characteristics of changes in the state of the cardiovascular and nervous systems, autonomic regulation, and metabolic parameters in winter swimmers at water temperatures from +0.5°C to +2.0°C over various distances and during a 10-min swim of 450–550 m. To that end, the following objectives are set:

(1) to assess myocardial conduction (duration of P, PQ, QRS, QT, QTc waves, heart axis) in cold-adapted winter swimmers at rest and its changes under the influence of swims of varying duration (25 m backstroke, 25 m and 200 m freestyle, and a 10-min swim of 400–450 m) at water temperatures from +0.5°C to +1.5°C;

(2) to investigate the influence of the diving reflex on myocardial conduction during cold-water swims by comparing 25 m backstroke and freestyle swims;

(3) to study changes in systemic hemodynamics (systolic and diastolic blood pressure, heart rate) during short-term and prolonged cold exposure;

(4) to assess changes in capillary blood glucose levels and simple sensorimotor reaction time as integral parameters of the stress-response and neuromuscular reaction to cold-water immersion.

MATERIALS AND METHODS

The study was conducted under competitive conditions and during training camps held in Pereslavl-Zalessky on January 12–14, 2024 (Friendship Cup) and in Moscow on February 23–24, 2024 (Friendship Cup). All participants were considered conditionally healthy, received medical clearance for competitions, were adapted to cold-water swimming, had at least two years of experience in winter swimming, and had completed the necessary cold-load training.

According to the criteria of the International Ice Swimming Association (IISA), the athletes were permitted to swim specific distances given the presence of a confirmation of swimming the corresponding distance in category "A" during their training process. The functional state of the participants was assessed after swims over distances of 25 m backstroke, 25 m and 200 m freestyle. Additionally, outside of competitions, a 10-min swim over a distance of 400 m was conducted. This distance, although complying with IISA requirements, is not currently regulated by the rules of winter swimming in the Russian Federation. Discussions are currently underway regarding the need to include this distance, which prompted us to conduct this study.

[1] Order of the Ministry of Sports of the Russian Federation No. 333 «On Recognition and Inclusion of Sports Disciplines and a Sport in the All-Russian Register of Sports and on Amendments to the All-Russian Register of Sports» dated 12.04.2022.

[2] The International Winter Swimming Association. General rules. https://iwsa.me/winter-swimming-world-championship/rules/

In total, 24 individuals were examined. These were 9 females (aged 23–55, mean age 39.1 ± 2.7 years); 3 males (aged 71 ± 3 years); and 12 male (aged 35–60, mean age 43 ± 1.8 years) athletes. Swims were conducted in the morning. Water temperature ranged from +0.5°C to +1.5°C under an air temperature from –15°C to –18°C. In accordance with the rules of the International Winter Swimming Association (IWSA and IISA), participants swam without wetsuits. For short-distance swims, athletes (men and women aged 23–39) with clearance for swimming and at least two years of cold-water swimming experience were randomly selected.

For the 350–450 m (10-min swim) group, 10 individuals — 9 men and 1 woman aged 35–55 (mean age 43 ± 2.3 years) — were selected. All had clearance for long-distance swims according to the IISA rules and the Winter Swimming Rules approved by the Russian Ministry of Sports.[3] Almost all athletes participating in the training camps and competitions who had clearance for the 400 m distance (10-min swim) were examined. These same swimmers were included in the groups for post-swim assessment after the 25 m and 200 m distances. According to the analysis of protocols, the swim times for 25 m ranged 12.4–32.0 s; the control time for 200 m swims was 5 min for men and 5 min 30 s for women.

Beginners in their first season were not included in the groups to exclude insufficiently adapted individuals to cold stress during category “A” swims. The groups were formed such that to proportionally match by age the composition of those engaged in cold-water swimming within the All-Russian Winter Swimming Federation.

The baseline assessment of the body’s functional state was conducted at 8:00–9:00 a.m. before food intake. To that end, methods available under competitive conditions were used: 12-lead electrocardiography (ECG) (recording duration 10 s, recording speed 50 mm/s) using a Polyspectrum-8/E cardioanalyzer and a Neurosoft electrocardiograph (Russia). The presence of arrhythmias and myocardial conduction were assessed: the duration of cardiac cycle intervals (in ms) — R-R, P, PQ, QRS, QT; the QTc index was determined using Bazett’s formula; the electrical axis of the heart (in degrees) was determined. To identify risks of a hypertensive response, blood pressure levels (BP in mmHg) were measured (A&D Medical UA-787 tonometer, Japan). The risk of a hyperglycemic response to cold-water swims was assessed by measuring capillary blood glucose levels (mmol/L) using a One Touch Select Plus device (LifeScan Europe GmbH, China).

The influence of water-cold immersion on the functional state of the nervous system and the speed of neuromuscular conduction was assessed by the time of a simple sensorimotor reaction (SSMR in ms) to a light stimulus (12 responses were recorded) using an UPFT-1/30 “Psychophysiologist” device (Medicom-MTD, Russia).

Anthropometric parameters of the swimmers were measured: height (in cm) using a wall-mounted medical height rod (tape measure) (KaWe, Germany) and body weight (in kg) using portable medical scales (VMEN-150-50/100-D2-A). The body mass index was calculated using the Quetelet formula, i.e., BMI = weight (kg) / height (m^2).[4] Functional parameters were recorded both before the swim (15 min prior) and immediately after the swim during recovery. Post-swim ECG, as well as blood pressure (BP) levels, were recorded at 5–7 min of recovery. Capillary blood glucose levels were determined within 7–10 min after the swim; assessment of the simple sensorimotor reaction to a light stimulus was conducted within 10–12 min after the swim.

During data analysis, pre- and post-swim parameters were compared for all distances, and parameters after all swims were also compared. For statistical data analysis, the GraphPad Prism 8 package for Windows 10 was used. The significance of differences for unpaired independent sample pairs was assessed using nonparametric Mann–Whitney *U* and Kruskal–Wallis tests. For paired related samples (“pre- and post-” swim), the Wilcoxon signed-rank test was used. In samples with normal distribution, the mean and standard error of the mean ($M \pm m$) were calculated for the groups as a whole. To assess the significance of differences, Student’s *t*-test and one-way ANOVA were used. The level of *p*-values < 0.05 was considered statistically significant. Additionally, for SSMR and ECG parameters, the statistical significance of changes was determined individually for each subject both pre- and post-swim. To assess the statistical significance of individual parameter changes, the nonparametric Wilcoxon signed-rank test was used.

RESULTS

Anthropometric parameters of amateur athletes adapted to cold-water swimming

The average height of women was 167.1 ± 1.9 cm (155–175 cm); weight — 64.4 ± 2.1 kg (53–72 kg); body mass index (BMI) — 22.7 ± 2.4 kg/m^2 (20.4–25.2 kg/m^2). The average height of men in the main group was 178.8 ± 4.1 cm (169–190 cm); weight — 80.9 kg (63–107 kg); BMI — 25.3 ± 4.5 kg/m^2 (20.1–34.3 kg/m^2). The height of the older men was 189 cm, 181 cm, 182 cm; weight — 103 kg, 84 kg, 89 kg respectively; BMI — 31.1 kg/m^2, 23.5 kg/m^2, 24.4 kg/m^2. The body mass index of the swimmers did not exceed normal values and averaged 22.7 ± 2.4 kg/m^2 (20.4–25.1 kg/m^2) for the group; one woman was found to be underweight (BMI = 17.9 kg/m^2). Among male winter swimmers, three individuals were identified with overweight and a BMI of 25.5–29.8 kg/m^2, and two individuals with body weight

[3] Order of the Ministry of Sports of the Russian Federation No. 1026 «On Approval of the Rules for the Sport ‘Winter Swimming’» dated 16.10.2024.
[4] Nuttall FQ. Body Mass Index: Obesity, BMI, and Health: A Critical Review. *Nutrition Today.* 2015;50(3):117–28. https://doi.org/10.1097/nt.0000000000000092

corresponding to first-degree obesity (BMI = 31.2 kg/m^2 and 34.5 kg/m^2).

It should be noted that all men with excess weight had been adapted to long-distance swims of 400 m and prolonged exposure to ice-cold water. The other five swimmers included in the 10-min swim group (350–450 m) had a body mass index close to the upper limit of the WHO normal range.[5]

Changes in myocardial conduction under the influence of swims of varying duration in open cold water

The analysis of baseline ECG, recorded at rest in athletes adapted to cold-water swimming, revealed a slowed conduction through the atria in 16 out of 24 individuals (P wave duration exceeded the norm >110–138 ms). In 4 athletes, slowed excitation propagation through the ventricles was observed (QRS 102–116 ms); and in 6 individuals, QTc exceeded the normal range (452–466 ms) (Table 1).

Swims over the distances were performed using the following swimming techniques: backstroke without facial immersion in water and freestyle, i.e., front crawl with facial immersion in water. More pronounced changes in myocardial conduction were identified during 25 m freestyle swims with facial immersion. On average across the group, a statistically significant slowing of impulse conduction velocity through the atria (increase in P wave duration) and from the sinus node to the ventricles (increase in PQ interval) was observed (Table 1). In 3 individuals, P wave duration significantly exceeded the norm (>120 ms) after the swim. The PQ interval significantly exceeded normal limits in 2 individuals (>210 ms). Overall, across the group, an increase in the duration of excitation propagation through the ventricles was observed in the form of a statistically significant prolongation of the QRS interval ($p < 0.05$); in 7 out of 17 individuals, this parameter significantly exceeded normal limits and surpassed 100 ms. A significant ($p < 0.001$) increase in the corrected QTc interval was also noted in 8 out of 17 swimmers, reaching 485 ms or more, which significantly exceeded normal values.

The most pronounced changes in myocardial excitation conduction were identified after long swims of 200 m and 400–450 m over 10 min. For instance, the duration of R–R intervals decreased statistically significantly after the 10-min swim in almost all athletes. In this setting, a

Table 1. Dynamics of myocardial conduction during swims of varying duration in cold water (t = +0.5°C)

Electrocardiogram parameters							
Heart rate, bpm	**RR mean, ms**	**P, ms**	**PQ, ms**	**QRS, ms**	**QT, ms**	**QT, s**	**QRS axis, degrees**
Baseline values, n = 24							
75.5 ± 2.4 (57–97)	810 ± 37 (620–1090)	112 ± 3 (90–138)	154 ± 3 (138–201)	93 ± 3 (108–116)	382 ± 7 (354–451)	425 ± 5 (395–466)	49 ± 9 (-24–95)
Swim 25 m backstroke (swim duration range 17–32 s), n = 13							
68.4 ± 3.9 (55–95)	906 ± 60 (718–1100)	115 ± 7 (80–148)	160 ± 5 (140–187)	98 ± 4 (84–112)	409 ± 13 (398–473)	434 ± 10 (409–455)	41 ± 14 (-32–96)
Swim 25 m freestyle (swim duration range 15–31 s), n = 17							
79.5 ± 3.7 (54–103)$^{\#}$	761 ± 35 (584–1106)$^{\#}$	139 ± 15 (102–210)$^{3*\#}$	170 ± 10 (126–234)*	100 ± 4 (74–116)*	410 ± 13 (374–392)	471 ± 15 (432–529)$^{2*\#}$	39 ± 18 (-42–88)
Swim 200 m freestyle (swim duration range 2 min 52 s — 5 min 3 s), n = 10							
92.4 ± 5.3 (59–105)*	670 ± 45 (569–1010)*	113 ± 3 (76–142)	160 ± 17 (140–182)	102 ± 6 (78–142)**	382 ± 11 (344–432)	470 ± 8 (429–501)*	45 ± 10 (15–95)
Swim, 10 min freestyle (350–550 m), n = 10							
95.9 ± 6.4 (85–114)^{2*}	645 ± 46 (528–703)^{2*}	115 ± 6 (80–152)^{2*}	129 ± 10 (86–162)$^{2*2\blacklozenge2\blacksquare}$	109 ± 7 (83–137)^{2*}	358 ± 17 (186–392)$^{3*\blacklozenge\circ}$	532 ± 19 (403–797)$^{3*3\blacklozenge2\blacksquare}$	71 ± 9 (36–90)^{2*}

Table compiled by the authors based on their own data

Note: * — $p < 0.05$; ^{2*} — $p<0.01$; ^{3*} — $p < 0.001$ — significance of differences between baseline and post-swim values; $^{\blacklozenge}$ — $p < 0.05$; $^{2\blacklozenge}$ — $p < 0.01$; $^{3\blacklozenge}$ — $p < 0.001$ — comparison after 10 min swims (350–450 m) freestyle and 25 m backstroke; $^{\blacksquare}$ — $p < 0.05$; $^{2\blacksquare}$ — $p < 0.01$ — comparison after 10 min swims (350–450 m) freestyle and 25 m front crawl; $^{\#}$ — $p < 0.05$ — comparison after 25 m backstroke swims and 25 m front crawl swims; data are presented as the mean value and standard error of the mean $M \pm m$, in parentheses — ranges of minimum and maximum values.

[5] World Health Organization (WHO). Body mass index (BMI). URL: https://www.who.int/data/gho/data/themes/topics/topic-details/GHO/body-mass-index (access data 07.10.2025).

statistically significant decrease in the PQ interval was recorded. The duration of myocardial repolarization remained within normal limits in 8 out of 10 swimmers; however, its frequency-corrected QTc value significantly exceeded normal limits (Table 1).

Thus, the most significant changes in the conduction of the bioelectrical signal in the myocardium were observed in swimmers during prolonged 10-min swims ($p < 0.01$). After short-distance swims, a slowing of conduction from the sinus node to the atrioventricular node was noted (an increase in PQ relative to the baseline, $p < 0.001$) (Table 1). Conversely, during prolonged swims conduction accelerated (a decrease in PQ relative to baseline, $p < 0.01$) (Table 1). The corrected QTc interval increased in proportion to the duration of the swims. The significance of the increase in this parameter after 10-min swims compared to 25 m swims was $p < 0.01$ relative to the baseline, $p < 0.001$.

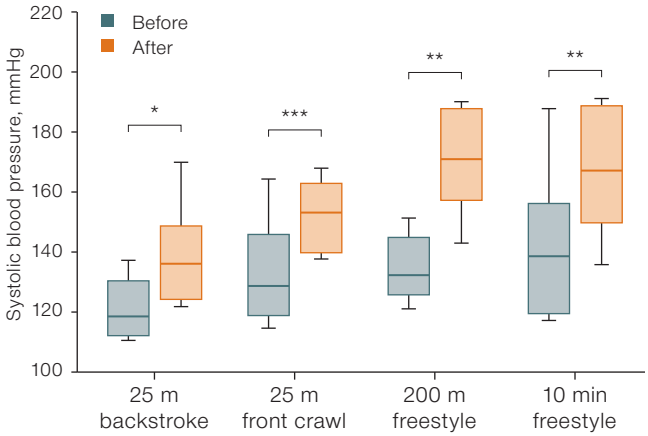

Figure prepared by the authors based on their own data

Fig. 1. Systolic blood pressure levels before and after swims at various distances

Note: * — $p < 0.05$, ** — $p < 0.01$, *** — $p < 0.001$ — statistical significance of differences between baseline and post-swim values.

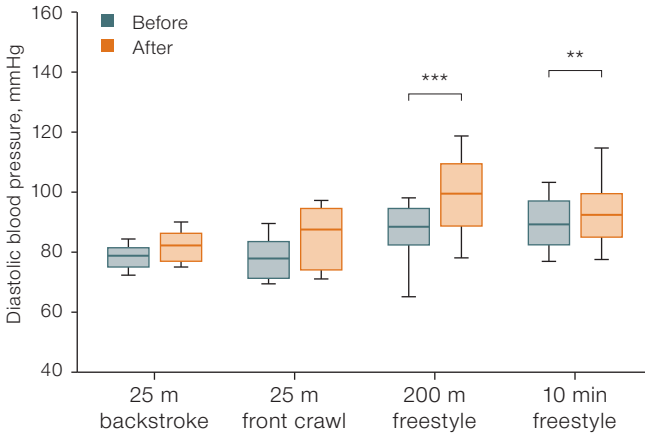

Figure prepared by the authors based on their own data

Fig. 2. Diastolic blood pressure levels (mmHg) before and after swims at various distances

Note: ** — $p < 0.01$, *** — $p < 0.001$ — significance of differences between baseline and post-swim values.

Changes in blood pressure levels under the influence of swims of varying duration in open cold water

At baseline rest, systolic blood pressure levels exceeded the optimal level (140 mmHg) in 3 individuals, and diastolic blood pressure (above 90 mmHg) was higher in 2 individuals. After the 25 m freestyle swim, the mean systolic pressure levels increased significantly (pre-swim 131.2 ± 2.6 mmHg, post-swim — 143.3 ± 4.1 mmHg ($p < 0.05$)) (Fig. 1). They remained within normal limits only in 18% of athletes. After the 25 m backstroke swim, systolic and diastolic pressure levels also increased; however, their values varied within normal limits in 50% of participants. The systolic pressure level after the 25 m front crawl swim significantly increased among the entire group (pre-swim — 131.2 ± 2.6 mmHg; post-swim — 147.9 ± 2.5 mmHg; $p < 0.001$). No statistically significant change in diastolic pressure after short-distance swims (25 m) was detected (Fig. 2).

After long swims of 200 m and 400–450 m, the mean blood pressure parameters increased significantly more than after short distances. At the same time, in 3 out of 10 swimmers, systolic and diastolic pressure levels remained within normal limits. In 2 athletes, systolic levels and in one athlete, diastolic levels significantly exceeded normal limits (systolic parameters exceeded 190 mmHg, and diastolic — 102 mmHg, respectively) (Fig. 1).

Changes in capillary blood glucose levels under the influence of swims of varying duration in open cold water

In all examined athletes, glucose levels before food intake did not exceed normal values (4.3–6.1 mmol/L). In some athletes, glucose levels before swims were slightly above normal. After 25 m freestyle swims, glucose levels increased in 85% of athletes (group mean pre-swim

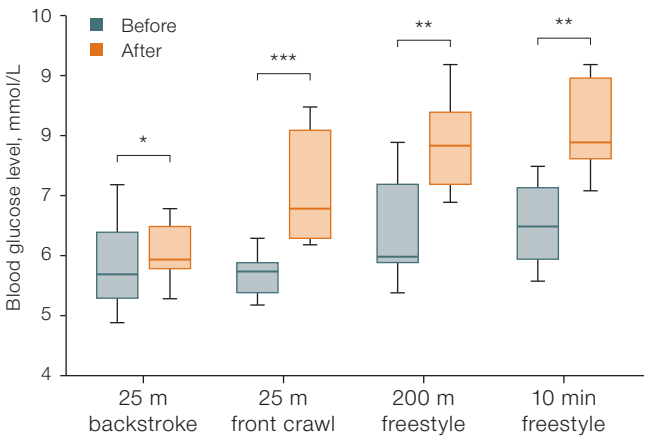

Figure prepared by the authors based on their own data

Fig. 3. Capillary blood glucose levels before and after swims at various distances

Note: * — $p < 0.05$; ** — $p < 0.01$; *** — $p < 0.001$ — significance of differences between baseline and post-swim values.

5.7 ± 0.1, post-swim — 6.9 ± 0.1; $p < 0.05$); during 25 m backstroke swims, increased glucose levels were noted in 70% of subjects (group mean pre-swim 5.9 ± 0.2, post-swim — 6.9 ± 0.2; $p < 0.05$). After swims of 200 m and 350–450 m (10-min swim), glucose levels increased in 9 out of 10 examined individuals. The mean glucose level before the swim was 6.2 ± 0.2, post-swim — 8.2 ± 0.25; $p < 0.01$ (Fig. 3).

Changes in sensorimotor reaction time under the influence of swims of varying duration in open cold water

After short-distance swims (25 m) backstroke and freestyle, the simple sensorimotor reaction time to a light stimulus changed insignificantly based on the group mean. According to individual indicators, it increased slightly in some swimmers and, conversely, decreased in others (3 athletes) (Table 2).

After the 200 m swim, this indicator increased statistically significantly in 6 out of 11 examined individuals, while it changed insignificantly at rest. After the 10-min swim, an increase in reaction time was observed statistically significantly in 9 out of 10 subjects (mean pre-swim — 263 ± 10.1 ms, post-swim — 328 ± 21.3 ms; $p < 0.01$) (Table 2).

DISCUSSION

The analysis of anthropometric indicators in amateur athletes adapted to cold-water swimming showed that the group mean did not exceed normal values. At the same time, in swimmers adapted to long-distance swims (10-min swim of 350–400 m), the body mass index was either at the upper limit of normal or even higher. The noted shifts are presented in the works of other authors [3].

The BMI indicator is an indirect criterion for the presence of adipose tissue in the body; in addition, it is internationally recognized as a marker of obesity and overweight[6] [4, 5]. At the same time, in athletically built individuals, BMI may be associated with developed muscle tissue rather than with adipose tissue. Traditionally, in cold-water swimmers, an elevated body fat level is linked to protection against core hypothermia [6–9]. Furthermore, cooling of a larger body with greater mass occurs more slowly [10]. However, contemporary studies have shown that the BMI of cold-water swimmers does not differ statistically significantly from that of classical swimmers in pools with normal water temperature [11].

Our data are consistent with the established concepts. Swimmers participating in short-distance swims under the extreme conditions of ice-cold water may have a low BMI, even near the lower limit of normal. However, only athletes with a sufficiently high BMI can withstand long-distance swims.

Our analysis of fasting-morning blood-glucose levels did not reveal individuals with hyperglycemia among cold-water swimmers. However, based on group means, capillary blood glucose concentration increased statistically significantly after the swims. During short-distance swims, the indicator was elevated in 80% of swimmers. After long-distance swims, an increase in glucose was observed in 90% of the examined individuals. A significant decrease in glucose levels in swimmers after the swims was not noted.

The increase in blood glucose levels during swims under competitive conditions in extremely cold water may be stress-induced [13–15]. Stress is considered an adaptive response of the body to a strong disturbing environmental stimulus [15]. The increased activity of the sympathoadrenal system in response to a set of stress factors not only increases the volume of substrate for oxidation in the form of glucose but also stimulates the activity of non-shivering thermogenesis. The latter is a mechanism of accelerated heat production through increased metabolic activity in brown (or beige in humans) adipose tissue. This occurs through the activation of β_2-adrenergic receptors (β_2AR) in brown adipocytes by the sympathoadrenal system, increasing cAMP levels with subsequent expression of the mitochondrial membrane protein thermogenin (uncoupling protein 1, UCP1). UCP1 allows energy to be dissipated as heat instead of producing ATP [16]. As previous studies have shown, adaptation to swimming in low-temperature water (from 0°C to +2°C) leads to a decrease in blood levels of adrenocorticotropic hormone (ACTH) and cortisol, while catecholamines remain at high levels [17]. Currently, there exists evidence that, in addition to fatty acid oxidation during thermogenesis activation in brown adipocytes, glucose utilization also increases [18–20].

Table 2. Simple sensorimotor reaction time, ms

Swim 25 m backstroke, *n* = 13		Swim 25 m freestyle, *n* = 24		Swim 200 m freestyle, *n* = 11		Swim 10 min, 350–400 m, freestyle, *n* = 10	
Before swim	After swim	Before swim	After swim	Before swim	After swim	Before swim	After swim
257 ± 6.4	250 ± 7.3	251 ± 6.8	247 ± 6.2	245 ± 6.4	256 ± 10.3	263 ± 10.1	328 ± 21.3**

Table compiled by the authors based on their own data

Note: ** — $p < 0.01$ — significance of differences between baseline and post-swim values; data are presented as the mean value and standard error of the mean *M* ± *m.*

[6] Thompson WR, Gordon NF, Pescatello LS. The American college of sports medicine's guidelines for exercise testing and prescription. Baltimore, MD: Williams & Wilkins; 2010. URL: https://acsm.org/education-resources/books/guidelines-exercise-testing-prescription/ (access data 07.10.2025).

However, as recent studies convincingly demonstrate [21], the primary oxidation substrates for both shivering and non-shivering thermogenesis are lipids (their share in heat production is 50%), 30% comes from muscle glycogen, 10% is provided by proteins, and only 10% by plasma glucose. This may explain the persistence of elevated blood glucose levels after swims of 200 m and 400–450 m (10-min swim).

The simple sensorimotor reaction time (SSRT) was used to assess the combined influence of competitive stress, the cold factor, and physical load on the functional state of the neuromuscular system. According to the results obtained, during 25 m swims (swim duration 15–30 s), no statistically significant changes were detected overall for the group. The stress impact (competitive and cold stress) is regarded as the main factor affecting the nervous system during short-distance swims. This is confirmed by the increased levels of capillary blood glucose. Moderate activation of the stress-implementing sympathoadrenal system can either accelerate or slow down processes in the CNS, depending on the body's stress resilience [22].

After the 200 m swim (swim durations from 2 min 51 s to 5 min 2 s), our analysis of individual indicators demonstrated a statistically significant slowing of SSRT in half of the examined individuals, while no significant changes were detected in the other half. During this swim, body cooling is likely to affect the speed of nervous processes, neuromuscular transmission, muscle response, and the overall sensorimotor reaction duration (especially in swimmers with swim times exceeding 3 min).

A more pronounced, statistically significant slowing of SSRT based on the group mean was identified during the 10-min swim. A slowing of SSRT was detected in 9 out of 10 swimmers. The primary probable factor determining this slowing is body cooling. For instance, some studies have shown that prolonged exposure to low temperatures impairs memory and reduces attention, affecting reaction speed and decision making. Sufficiently long immersion in cold water leads to a drop in brain temperature by fractions of a degree, causing cognitive impairments due to slowed neural conduction and synaptic transmission mechanisms [23–25].

Our analysis of the dynamics of cardiovascular system indicators revealed a dependence of their changes on the duration of exposure to cold water. The baseline blood pressure values, on average for the group, corresponded to age norms. During 25 m swims, systolic pressure increased statistically significantly for the group as a whole, while diastolic pressure increased only slightly. However, it should be noted that in two examined individuals, it exceeded normal limits: systolic pressure increased above 160 mmHg, and diastolic pressure reached 104 mmHg. During short swims, the main factor increasing blood pressure is likely to be the activation of the stress-implementing sympathoadrenal system. During longer swims of 200 m and 400–450 m, in addition to the stress response, protective reactions against heat loss contribute to increased blood pressure, specifically sustained prolonged constriction of peripheral vessels, which increases peripheral resistance. A decrease in systolic pressure with a simultaneous increase in diastolic pressure, a reduction in pulse pressure, combined with a decrease in heart rate, was observed in one swimmer. Such a bodily response to the considered load should be considered unfavorable.

ECG analysis at baseline revealed slowed conduction through the atria in 66% of the examined swimmers. In clinical practice, this finding is considered unfavorable, being associated with signs of atrial chamber enlargement and atrial conduction block. It is also viewed as a risk factor in various clinical events, such as atrial fibrillation and ischemic stroke [26–28]. However, widening of the P wave may be due to a physiological condition often observed in athletes training in the aerobic power zone. In this case, P wave widening may be related to atrial hypertrophy resulting from adaptation to this type of activity [29, 30].

Cold-water swimming is an aerobic activity [31, 32] that places a significant load on the body's gas transport systems; therefore, it is quite reasonable to assume that it exerts a substantial load on the heart, contributing to myocardial hypertrophy and dilation of the heart chambers, including the atria.

Comparison of changes in myocardial conduction after 25 m backstroke and freestyle swims with facial immersion showed a more pronounced slowing of conduction during swims with facial immersion. This may be related to the activation of the so-called diving reflex and enhanced vagal parasympathetic influences on the sinus node of the heart [2]. It was also noted that the slowing of conduction, especially in the atria (P wave duration), immediately after swims varied among the examined individuals. In one swimmer, the conduction duration decreased; in three, it changed insignificantly, remaining within normal limits; in five, it exceeded the upper limit of normal (112–122 ms); and in eight, it significantly exceeded the norm (125–210 ms). We believe this is due to different myocardial reactivity to the influences of the *n. vagus* during the implementation of the diving reflex while swimming with facial immersion [33].

During longer swims of 200 m and 400–450 m, conduction velocity in the atria returns to the baseline levels. In our opinion, this is due to the onset of manifestation of sympathetic, along with parasympathetic, effects on the myocardium associated with cold stress. It is known that parasympathetic cholinergic effects are realized faster (<1 s from the onset of exposure) than sympathetic effects (>5 s from the onset of exposure) [34].

The increase in blood glucose levels during swims, especially during long-distance swims, indicates that the body is under stress. The duration of bioelectrical signal conduction through the ventricular myocardium progressively increases (increase in QTc) in accordance with the duration of exposure to water. This finding can be explained by several factors. First, electrolyte imbalances (e.g., hypokalemia) associated with physical exertion occur against the background of high catecholamine levels

[35] that are particularly elevated during cold stress in long swims. Second, the use of QT-prolonging medications or those stimulating metabolic changes. However, amateur athletes who participated in the swims had been previously warned about the undesirability of taking such substances. Third, cases of hereditary predisposition to QT interval prolongation, such as a mutation in the *KCNQ1* gene, should not be excluded. Physical exertion and high catecholamine levels associated with cold stress in such athletes may be a triggering factor [36]. It should also be noted that an increase in the corrected QT interval (QTc) was observed in all swims with facial immersion in water, but not in backstroke swims. In our opinion, this is further evidence that the diving reflex, activated during facial immersion while swimming in cold water, plays a significant role in generating risks for cardiac arrhythmias.

Our findings are supported by data obtained in a joint study by Slovenian and French researchers, who also observed an increase in the QTc interval during long-distance swims, although in a less extreme cold water (at 15°C). However, these researchers did not establish a direct correlation between the degree of body cooling and the increase in the QTc indicator. In our studies, a pronounced increase in QTc duration, exceeding 500 ms, was observed during the longest swims. A dependence between the conduction of the electrical signal in the myocardium and the degree of body temperature reduction may exist. Further research is needed to confirm this assumption. It can be hypothesized that the prolongation of the QTc interval arises from the cumulative effect of several factors, such as cold and competitive stress, electrolyte imbalance due to intense physical exertion, body cooling, cholinergic reactions of the diving reflex, and genetically determined characteristics of the organism [37, 38].

Slowing of myocardial conduction may also be associated with high myocardial reactivity to the cholinergic effects of the *n. vagus* [33] during the implementation of the diving reflex upon immersion in water. In this case, the additional factor of low temperature, causing body cooling, may act as a trigger for cardiac arrhythmias or even lead to cardiac arrest. Such cases have occurred in the practice of cold-water swimming and are described in the literature. Therefore, we believe that for permission to engage in cold-water swimming, an additional assessment of the response of the cardiovascular system to cold-water immersion should be conducted.

Hence, a dependence of hemodynamic and neurophysiological reactions on the duration of the swim has been demonstrated. At all distances, systolic blood pressure and glucose levels increased, while a pronounced slowing of the simple sensorimotor reaction and the most significant prolongation of the QTc interval were recorded during 10-min swims. This complements the theory of a stepped stress response to cold and physical exertion and integrates cardiac, metabolic, and regulatory changes of the neuromuscular system into a unified functional model.

Our results indicate the role of the diving reflex: swims with facial immersion in ice-cold water cause a more pronounced slowing of conduction and prolongation of the QTc interval than backstroke swims. This clarifies the mechanism of “autonomic conflict” (simultaneous activation of sympathetic and parasympathetic systems) as a risk factor in arrhythmias during cold-water immersion. Similar mechanisms have been also discussed in the international literature on autonomic conflict and arrhythmias during cold water immersion.

Our results may be of interest to cardiologists and functional diagnostic physicians. The data obtained demonstrate the necessity of introducing an additional criterion into the medical clearance for sports cold-water swimming, i.e., the response of the cardiovascular system to cold-water immersion. They can be used in categorizing competition distances and regulating their sequence in event programs; developing protocols for admission, monitoring, and rehabilitation of winter swimmers; and creating educational programs for coaches and beginners on safely entering cold-water swimming.

The limitations of our study are related to the small sample size (24 individuals) and the predominance of well-adapted amateur athletes, thus impeding direct extrapolation of the results to completely non-adapted beginners. Future research should compare swims in cold water with results from swims in a comfortable-temperature water. This would allow for a clearer separation of the contributions of chronic aerobic training and the cold factor itself to the formation of baseline ECG changes (widening of P and QTc). It should also be noted that we assessed the effects of hypothermia on myocardial conduction and nervous system processes indirectly, based on QTc and SSRT time, which requires confirmation in studies with direct monitoring of core body temperature. It would also be important to evaluate the effect of body composition (fat mass, subcutaneous adipose tissue thickness). In addition, the role of the fat component in heat conservation and tolerance of long distances was assessed only via BMI, thus requiring further research. Studying polymorphisms in genes encoding potassium channel proteins associated with QT prolongation appears promising. This could identify individuals with a potential risk of QTc prolongation under conditions of cold-water swimming.

CONCLUSIONS

1. Slowing of electrical impulse conduction through the atria (P wave duration > 0.11 ms, exceeding the upper limit of normal) was established at baseline rest in 67% of the examined swimmers; after short-distance swims (25 m), P wave duration significantly exceeded the upper normal limit in 85% of the examined.

2. A direct relationship was identified between the QTc indicator and both the distance and the duration of its completion. During the 10-min swim, an increase in QTc interval duration was observed in all swimmers. In 3 out of 10 athletes, QTc was at the upper limit of normal, while

in 5 athletes, it significantly exceeded the upper normal limit (QTc > 500 ms).

3. Comparison of myocardial conduction after short-distance swims (25 m) front crawl with facial immersion vs. backstroke swims revealed a statistically significantly more pronounced slowing of biopotential conduction through the atria and ventricles of the myocardium. This is likely due to the activation of the diving reflex and enhanced cholinergic influences of the *n. vagus* on the myocardium.

4. A significant increase in systolic blood pressure was established after swims at all distances; a statistically significant increase in diastolic blood pressure based on the group mean was observed only after the 10-min swim.

5. A statistically significant increase in blood glucose levels based on the group mean after swims at all distances compared to the baseline reflected the presence of stress even in swimmers adapted to cold-water swimming.

6. An increase in the simple sensorimotor reaction time to a light stimulus relative to the baseline was identified after prolonged 10-min swims of 350–450 m, reflecting a slowing of processes in the central and peripheral nervous systems.

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