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Predicting the Effectiveness of Physical Therapy in Hockey Players after Cerebral Concussion

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Abstract The aim is to develop a prognostic model of rehabilitation for the restoration of motor and cognitive functions in hockey players after a cerebral concussion. The research covered 80 hockey players aged from 17 to 51. Research methods: generalization of scientific and methodological literature, clinical, instrumental, functional methods, and methods of mathematical statistics. The greater effectiveness of the developed physical therapy program in comparison with the standard one has been proved according to the following indicators: limitation of life-sustaining activities by 26.0 ± 2.1%, tone of the autonomic nervous system according to the Kerdo index by 9.9 ± 0.8%, heart rate variability according to statistical indicators of standard deviation of cardiac intervals and variation range by 4.6 ± 0.3% and 28.2 ± 3.5%, respectively, according to the index of autonomic balance by 33.7 ± 4.9%, decrease in the stress index of regulatory systems by 22.5 ± 4.6%, decrease in the time of the test performance with tandem walking and cognitive task by 20.1 ± 1.6%, increase in the score on the Montreal Cognitive Assessment Scale by 12.4 ± 2.0%. According to prognostic model, the most significant factors aggravating the prognosis are the level of headache according to the visual analogue pain scale (regression coefficient B = -0.12), the number of repeated cerebral concussions (B = -1.02); prognostically favorable factors are the general level of cognitive functions (B = 0.03), a lower level of sympathicotonia according to the autonomic balance index (B = 0.03) and the Kerdo index (B = -0.08). The developed model provides results within 20.0% of the existing actual values, which indicates satisfactory and effective work (determination coefficient of 54.0 %, $p < 0.05$).

Keywords Athletes, Brain, Injury, Rehabilitation, Autonomic Regulation, Motor and Cognitive Disorders

1. Introduction

Timely prescription of optimal physical therapy for athletes after cerebral concussions (CCs) is receiving increasing attention not only from athletes and coaches but also from healthcare professionals [1, 2]. This is especially important for contact sports, where there is the highest probability of traumatic injury to the neck and head [3], including ice hockey, which can cause long-term disabling effects [4]. Despite the existence of an approved mechanism for the management of athletes after CC, in particular the SCAT 5 protocol [5], there is no consensus among specialists on the content, dosage features, and optimal time to start therapeutic and training loads during the recovery of such athletes [6, 7, 8]. The existing disagreements in the views of specialists on the timing and content of rehabilitation are associated with the need to apply forced approaches for the rapid restoration of sports performance capacity, which often goes contrary to the consideration of violations of regulatory mechanisms, especially the autonomic nervous system.

Predicting the recovery time after CC is of particular interest among researchers [9]. Characterizing the recovery, the problem can be divided into the recovery of physiological systems, cognitive, neuropsychological, and emotional states [3, 4]. On the part of sports provision, the most attention should be paid to the issues of the recovery time in terms of general and special physical performance capacity [2, 7]. The main directions of the research in predicting the consequences of CCs and the possibility of returning an athlete to professional activity are focused on finding the most influential factors, the main of which are genetic, age, sex, clinical, especially the severity of damage to the central nervous system [10, 11]. However, despite the considerable interest of researchers in the problem of predicting the consequences of CCs in sports, effective models have not yet been formed.

At the preliminary stages of the research, we found a significant impact of autonomic nervous system (ANS) dysregulation on the processes of early recovery in hockey players after CCs [12]. In particular, the necessity of taking into account the tone of the ANS, the level of stress of regulatory systems, and the level of headache when planning rehabilitation and training loads in hockey players after CCs was substantiated [13]. In addition, the negative impact of repeated CCs during a sports career on cognitive functions in the long term has been proved [14].

Thus, the scientific substantiation of the factors predicting the effectiveness of rehabilitation measures for hockey players who have undergone CCs is relevant.

1.1. The Aim

The research aims to develop a prognostic model of rehabilitation for the restoration of motor and cognitive functions in hockey players after a cerebral concussion.

1.2. The Hypothesis

It is assumed that the establishment and substantiation of the factors influencing the effectiveness of rehabilitation measures will be an effective tool for predicting the recovery time of general and special working capacity, and hence the timing of the return of hockey players to professional activities after CCs.

2. Materials and Methods

2.1. Participants

The research involved 80 hockey players aged 17 to 51 years. The first stage of the research involved the examination of 20 ice hockey players (17 men and 3 women), who had already finished their sports activities at the time of the examination. The average age of hockey players was 34.0 ± 9.4 years. All players were members of the national teams of Ukraine and had a high level of sports mastery. The II and III stages of the research during 2020-2022 covered 60 hockey players of different sports qualifications aged 17 to 34 years (average age was 23.3 ± 4.3 years) with a cerebral concussion. The formed groups at the II and III stages of the research did not differ in age, weight, height, body mass index (BMI), and length of professional experience, which proves the homogeneity of the groups at the beginning of the research ($p > 0.05$) (Table 1). The athletes were on the dispensary account in the institutions of the system of providing medical and physical training assistance in Ukraine during the last year. Written informed consent was obtained from all athletes who participated in the research.

Table 1. Analysis of group homogeneity at the beginning of the research (M ± SD)

Indicator		Main group (n = 30)	Control group (n = 30)	Statistical criterion	p
				Mann-Whitney U-criterion	
Age, years		24.3 ±4.6	22.7 ±4.2	358,5	0.17
BMI, kg/m^2		25.1 ±2.2	24.7 ±1.1	381,5	0.31
Weight, kg		80.3 ±11.6	80.8 ±4.8	428,5	0.75
Height, cm		178.4 ±10.3	181.0 ±3.2	371,5	0.24
Length of professional experience, years		8.1 ±1.5	8.2 ±1.7	441,0	0.87
				Pearson's Chi-square	
Sex	Males, n (%)	26 (86.7)	27 (90)	0.22	1.46
	Females, n (%)	4 (13.3)	3 (10)		

Notes: p – the level of statistical significance according to the indicator in the comparison groups.

2.2. Research Procedure

The research, according to its design concept, is retrospective and prospective, open (unblinded), and non-randomized. The first stage of the research, during 2019-2020, involved the study of the long-term consequences of CC in professional hockey players who completed their training and competitive activities. On average, 4.75 ±3.26 years (from 1 to 12 years) passed after the completion of sports performances. In order to establish the acute, post-acute and long-term consequences of CC the II and the III stages during 2020-2022 involved the study of consistently included 30 hockey players with CC who underwent rehabilitation according to a standardized program in compliance with the SCAT 5 protocol (the control group) [1, 5], in particular, the physical therapy program in the control group lasted 4 weeks. The athletes were prescribed physical and cognitive rest on the day and the next day of receiving a CC, and the physical therapy included cyclic aerobic exercise on an exercise bike from the third day during the first week, and then on a treadmill, taking into account the target zone for a heart rate of 80-90% of the tolerance threshold for 20 minutes a day for 3 weeks after the concussion. Balance and coordination exercises were also used for 15 minutes daily for the first 2 weeks and every other day during the 3rd and 4th weeks of rehabilitation. 30 hockey players with CCs were included in the research afterward, who were managed in accordance with the developed differentiated rehabilitation program taking into account the tone of the ANS, the stressindex of regulatory systems (SI) and the level of headache according to the visual analogue pain scale (VAS) (the main group), in particular, therapeutic breathing exercises with an emphasis on exhalation, therapeutic exercises for coordination and balance (from the second day – exercises for training static balance, and from the third day – exercises for training neuromuscular control and dynamic balance) were used even from the second day after CC at the level of stress of regulatory systems below 200 units (according to the SI) and if the level of headache on the VAS was below 3 points (i. e. 0-2 points); aerobic exercises and exercises for the development of cognitive functions with the simultaneous performance of two tasks (with physical and mental load), proprioceptive training on an unstable platform were prescribed if the SI was less than 150 units. The duration of the intervention was 12 weeks. The examination was conducted on the 1st, 2nd, 3rd, 7^{th,} and 90th days after CC. Therapeutic sessions took place daily during the first 7 days (or until the start of training) and twice a week from the second week (or after the start of training). The duration of therapeutic sessions was 45 minutes. The duration of the additional session was 30 minutes upon the training resumption.

2.3. Research Methods

Research methods included the analysis and synthesis of literature sources, clinical, instrumental, and functional methods as well as methods of mathematical statistics. The first stage involved the examination of the long-term consequences of CC in retrospect using the questionnaire to study the passport part, sports anamnesis, the number and nature of CCs, the peculiarities of providing rehabilitation management, and return to training and competitive activities. Prospectively, they studied anthropometric data, the presence and nature of clinical manifestations, in particular, complaints of headache, neurological manifestations, and the nature of cognitive impairment using mini-mental state examination (MMSE) [15, 16].

The level of headache was determined by the VAS [17], physical development was studied using the method of anthropometry [18], the Kerdo index (KI) was calculated to establish the state of autonomic regulation [19]; the study of heart rate variability (HRV) was used to characterize the state of autonomic regulation, in particular by the index of autonomic balance (IAB) [20], the calculation of the stress index of regulatory systems (SI) [21]; the test with tandem

walking and the cognitive task was used to assess the impairment of the ability to simultaneously perform a motor and cognitive task [22], treadmillergometry was performed to determine the tolerance to physical activities [23], and the Borg scale was used [24]; the level of cognitive function was studied using the Montreal Cognitive Assessment Scale (MoCA) [25], the mini-mental state examination (MMSE).

2.4. Statistical Analysis

Statistical processing of the obtained results was carried out by methods of variation statistics using the STATISTICA 6.1 software package (number AGAR909E415822FA). The compliance of the data distribution with the normal law (Gauss' law) was assessed using the Shapiro-Wilk W-test. The results were presented as M ± SD (M ± m), where M is the arithmetic mean, m is the mean error of the arithmetic mean, and SD is the mean-square deviation. Since the distribution of most indicators differed from the normal one ($p < 0.05$) according to the results of the Shapiro-Wilk W-test, the Mann-Whitney U-criterion was used to compare groups based on quantitative data. Pearson's Chi-square test was used to compare qualitative indicators. The Craskell-Wallis criterion and Kendall's concordance coefficient were used to analyze multiple comparisons in the dynamics of recovery. The regression analysis was used to build a model of rehabilitation efficiency. The first stage of the regression analysis included the selection of the factors to be analyzed. Taking into account that 60 athletes took part in our research, the estimated number of influencing factors was chosen not more than 6 factors at the end of the analysis. We estimated the multicollinearity of the factors (correlation coefficient $r > 0.7$) that were analyzed at the second stage of the research. The correlation analysis was applied for this purpose. The third stage of the analysis provided for the study of the relative importance of multicollinear factors to objectify their value by standardized Beta coefficient using the regression equation. To assess the quality of the preliminary regression model, the fourth stage included the analysis of the residuals (differences between the actual response values and the values predicted by the regression equation) in terms of normality of distribution and dependence of the residuals predicted by the regression equation on the response values. The dependence of the residuals on the values predicted by the regression equation was checked by constructing a scatter diagram. The next fifth stage provided for the acceptability assessment of the regression model as a whole. The analysis of variance was conducted and the statistical reliability of the model was analyzed for this purpose. The sixth stage involved the analysis of the value of the coefficient of determination (R^2), which characterizes the share of changes in the response factor under the influence of all factors included in the selected model. The seventh stage provided for the construction of the regression equation. The last eighth stage made provisions for the practical test of the developed regression model. The level of threshold statistical significance of the research results was chosen as $p < 0.05$.

2.5. Ethics of the Research

The research was carried out within the framework of research works of the Department of Physical Rehabilitation, Sports Medicine and Valeology of Dnipro State Medical University referred to as "Medical and pedagogical support of physical rehabilitation, sports, and health training" (state registration No. 0116U004468, execution period 2017-2021) and "Medical, physiotherapeutic and ergo therapeutic support of sports, health and rehabilitation training" (state registration No. 0121U114435, execution period 2022-2026).

The research was conducted by the principles of the Declaration of Helsinki of the World Medical Association referred to as "Ethical Principles for Medical Research Involving Human Subjects" (amended in October 2013). The Commission on Biomedical Ethics of the State Institution "Dnipropetrovsk Medical Academy of the Ministry of Health of Ukraine" (now Dnipro State Medical University) granted permission to conduct the research (Protocol No. 8 of October 17, 2018) and revealed that no violations of moral and ethical standards were found during the research.

3. Results

It is important to control the state of ANS regulation to solve the issues of admission to rehabilitation and sports loads after CC. All hockey players who participated in the research were professional athletes characterized by the predominance of the tone of the parasympathetic ANS. The study of the state of autonomic balance in the KI on the first day after CC indicated sympathicotonia in all athletes. At the same time, there was no statistically significant difference between the groups at this stage of the research (Table 2). Positive dynamics of the KI were observed in both observation groups during the application of physical therapy programs ($p < 0.05$). However, it was statistically and significantly better in the main group. The research also evaluated the ratio of the parts of regulation by the KI at the end of 90 days after CC. The results of the comparison indicate a higher average level of the KI in the main group compared to the control group ($p < 0.05$), which confirms a better restoration of the advantage of parasympathetic tone in the regulation inherent in the normal regulation of professional athletes.

Table 2. Dynamics of clinical indicators of autonomic regulation in the process of rehabilitation (M ± SD)

Indicator	Observation groups		Mann-Whitney U-criterion	Level of statistical significance (p)
	Main (n = 30)	Control (n = 30)		
KI 1, %	- 15.7 ±1.7	- 15.5 ±2.3	406.0	0.52
KI 2, %	- 13.3 ±1.9	- 14.0 ±2.3	292.5	0.02
KI 3, %	- 9.5 ±2.3	- 12.3 ±2.3*	178.0	0.01
KI 7, %	- 6.5 ±2.8	- 10.1 ±2.5*	167.0	0.01
KI 90, %	9.5 ±3.4	7.2 ±3.6*	262.0	0.01

Notes: * - $p < 0.05$ is a statistically significant difference in comparison between the main and the control groups; KI 1, 2, 3, 7, 90 – the Kerdo index values on the 1st, 2nd, 3rd, 7th, 90th days after CC.

Table 3. The level and dynamics of the stress index of regulatory systems in the process of rehabilitation of hockey players after cerebral concussion (M ± SD)

Indicator	Observation groups		Mann-Whitney U-criterion	Level of statistical significance (p)
	Main (n = 30)	Control (n = 30)		
SI 1, units	197.6 ±26.4	205.0 ±26.0	344.0	0.12
SI 2, units	184.9 ±18.5	183.8 ±17.2	437.5	0.82
SI 3, units	113.0 ±29.6	170.0 ±15.2*	12.0	0.01
SI 7, units	86.8 ±32.1	153.9 ±15.7*	30.5	0.01
SI 90, units	71.4 ±12.2	103.1 ±15.9*	43.0	0.01

Notes: * - $p < 0.05$ is a statistically significant difference in comparison between the main and the control groups; SI 1, 2, 3, 7, 90 –the indicators of the stress index of regulatory systems during the 1st, 2nd, 3rd, 7th, 90th days of observation, respectively.

Characteristic confirmation of the dynamics of autonomic regulation indicators was established by the IAB, as a more sensitive indicator of the parasympathetic-sympathetic ratio. Sympathicotonia was determined in all athletes immediately after CC. The level of the IAB decreased to 37.6 ± 3.7 units and 35.7 ± 4.6 units in the main and the control groups, respectively. At the same time, there was no statistically significant difference in the observation groups, which indicates their homogeneity ($p > 0.05$). As early as the third day after CC there were 8 (26.7 %) hockey players in the main group who had normotonia (Pearson's chi-square – 9.23, $p = 0.002$). Only during the seventh day, 10 athletes (33.3 %) of the control group had normotonia, and the remaining 20 (66.7 %) had sympathicotonia. Herewith, normotonia was fixed in 18 (60.0 %) cases in the main group, the rest – 12 (40.0 %) still had sympathicotonia that indicated a statistically significant difference from the similar level of the IAB in the control group (Pearson's chi-square – 4.29, $p = 0.04$). Analyzing the changes in autonomic regulation by the IAB in 90 days after CC, a large number of sportsmen with signs of sympathicotonia were recorded in the control group. Thus, the IAB was determined at a level lower than 56.74 units in 14 persons (46.7 %), which indicated sympathicotonia. At the same time, there was not a single athlete with an IAB of more than 93.26 units, which indicates the absence of signs of parasympathicotonia. The rest of the players, in particular, 16 people (53.3 %), had the IAB at the level of normotonia. The situation in the main group was fundamentally different in the analysis of the long-term consequences of CC, in particular, there was not a single athlete with sympathicotoniaon the 90th day of observation. At the same time, 13 (43.3 %) hockey players were diagnosed with normotonia, and 17 (56.7 %) players had parasympathicotonia, which was also statistically and significantly better than in the control group (Pearson's chi-square – 31.3, $p = 0.0001$).

Stress and overstress of regulatory systems by the indicator of the SI were established in hockey players after CC (Table 3). Gradually, according to the obtained data, the level of SI during rehabilitation was decreasing and showed that none of the hockey players of both groups was in the zone of stress on the 90th day after CC. However, a detailed comparative analysis of the level of SI in the groups indicated that starting from the third day of rehabilitation in the main group, there was a statistically significant lower level of SI compared to the control ($p < 0.05$). A statistically significant difference between the groups of sportsmen by the level of the SI was established also on the 7th and the 90th days after CC.

Table 4. Dynamics of indicators of the ability to perform the test with tandem walking in the process of rehabilitation (M ± SD)

Indicator	Observation groups		Mann-Whitney U-criterion	Level of statistical significance (p)
	Main (n = 30)	Control (n = 30)		
TWC 1, seconds	19.3 ±0.6	19.0 ±1.0	324.5	0.06
TWC 2, seconds	19.1 ±0.6	18.9 ±0.9	355.5	0.16
TWC 3, seconds	19.0 ±0.6	18.9 ±0.8	356.0	0.16
TWC 7, seconds	17.9 ±1.1	18.8 ±0.8*	238.5	0.01
TWC 90, seconds	17.8 ±1.1	18.7 ±0.7*	249.5	0.01

Notes: * - $p < 0.05$ is a statistically significant difference in comparison between the main and the control groups; TWC 1, 2, 3, 7, 90 – results of the test with tandem walking and cognitive task on the 1st, 2nd, 3rd, 7th and 90th days of observation, respectively

Table 5. Dynamics of the level of cognitive functions according to the MoCA test in hockey players after cerebral concussion (M ± SD)

Indicator, points	Observation groups		Mann-Whitney U-criterion	Level of statistical significance (p)
	C	M		
1st day of rehabilitation				
Executive functions	0.67 ±0.21	0.65 ±0.19	375.0	0.27
Visual and constructive functions (cube and clock)	3.43 ±0.50	3.27 ±0.45	450.0	0.99
Attention	3.90 ±0.66	4.13 ±0.73	370.0	0.24
Speech disorders	1.77 ±0.43	1.80 ±0.41	435.0	0.82
Ability to abstract, delayed repetition	2.96 ±0.49	3.17 ±0.46	370.5	0.24
Orientation	5.83 ±0.38	5.73 ±0.45	405.0	0.51
Naming	2.51 ±0.22	2.67 ±0.18	439.5	0.87
90th day of rehabilitation				
Executive functions	0.69 ±0.25	0.71 ±0.29	395.0	0.42
Visual and constructive functions (cube and clock)	3.67 ±0.48	3.80 ±0.48	435.0	0.82
Attention	3.87 ±0.51	4.07 ±0.52	372.0	0.25
Speech disorders	1.90 ±0.31*	2.07 ±0.25	378.0	0.04
Ability to abstract, delayed repetition	3.57 ±0.50	3.73 ±0.45	375.0	0.27
Orientation	5.90 ±0.31	5.93 ±0.25	435.0	0.82
Naming	2.97 ±0.18	2.99 ±0.20	262.0	0.01

Notes: * - $p < 0.05$ in comparison between the observation groups during a certain day of rehabilitation; C, M – control and main groups, respectively.

The research also examined the ability of hockey players after CC to simultaneously perform dual-task tests (physical and cognitive). The first day revealed the worst ability of the comparison groups to simultaneously perform motor and cognitive tasks (TWC). There was no statistically significant difference between the groups ($p > 0.05$, Table 4). During rehabilitation, positive dynamics were observed in the ability to simultaneously perform motor and cognitive tasks in both groups ($p < 0.05$). The analysis of the TWC test results indicated that the most positive dynamics were recorded in the main observation group, which was established during visits on the 7th and the 90th days ($p < 0.05$). This proves the effectiveness of the use of cognitive exercises, which were included in the developed complexes of physical therapy.

There was no statistically significant difference in the components of cognitive function according to the MoCA test between the comparison groups at the beginning of the research ($p > 0.05$, Table 5).

The analysis of the data in Table 5 showed that during rehabilitation a statistically significant difference between the observation groups was noted only in terms of "Speech disorders" ($p < 0.05$). This indicator was better in the main group. However, a better trend was observed in the main group according to most cognitive components, which led to statistically and significantly better dynamics of the

overall MoCA points compared to the control group (day 1 – Mann-Whitney U-criterion = 439.5, Z = -0.16, p = 0.88, day 90 – U-criterion = 262.0, Z = -2.78, p = 0.01).

Of particular interest is the question of the cumulative effect due to the accumulation of CCs during a hockey player's career. The value of MoCA was compared by dividing the athletes into groups depending on the number of CCs obtained during their professional careers. The results of the analysis indicated a statistically significant decrease in the value of MoCA with an increase in CCs of more than 1 during a sports career, which should be taken into account when predicting the effectiveness of physical therapy (Table 6).

The importance of restoring the ability of a player for modern hockey who has suffered CC to decide in a rapidly changing environment became the basis for building a model of rehabilitation effectiveness. Therefore, the results of the TWC test on the 90th day after CC were chosen to characterize the effectiveness of rehabilitation. The evaluation of the impact factors was carried out on the third day after CC. Quantitative factors such as the level of headache according to the VAS, IAB, SI, the level of cognitive impairment according to the MoCA test, and the number of repeated CCs were chosen as factors of influence.

Subsequently, the relative importance of multicollinear factors was studied to objectify their significance by standardized Beta coefficient using the regression equation (Table 7).

The next stage provided for the assessment of the acceptability of the regression model as a whole. To do this, we analyzed the variance and analyzed the value of statistical reliability of the model (Table 8), according to which the built model is qualitative and acceptable.

Table 6. The level of cognitive functions in hockey players depending on the number of cerebral concussions (CCs) received during their career (M ± SD)

Number of CCs	Total number of hockey players	MoCA test average score	Craskell-Wallis criterion	Level of statistical significance (p)
1	7	28.7±1.4*		
2	3	26.7±1.2	3.84	0.03
3	6	27.7±1.6	3.68	0.04
4 and more	4	26.7±1.5	3.79	0.04

Notes: * - $p < 0.05$ in the comparison between the subgroup with 1 CC and the corresponding subgroups.

Table 7. Results of the adjusted regression analysis of the selected impact factors (n = 60)

Factors	Standardized Beta coefficient	B	p
Limitations of life-sustaining activity according to the VAS(points)	- 0.09	- 0.12	0.04
Kerdo index, %	- 0.21	- 0.08	0.049
IAB, units	0.17	0.03	0.049
MoCA, points	0.04	0.03	0.04
Number of CCs	0.50	- 1.02	0.04
Independent regression coefficient	-	5.27	0.02

Notes: B– correlation coefficient; p – the statistical significance of differences.

Table 8. Acceptability analysis of the regression predicting model in general

Indicator	Sum of squares	df	Average	F	p
Regression	30.7	5	5.11	10.4	0.0001
Excess	26.2	53	0.49		
Total	58.8				

Further, the value of the coefficient of determination (R2) was analyzed, which characterizes the share of changes in the response factor under the influence of all factors included in the selected model. It was found that R2 is equal to 0.54 and changes in the response by 54 % are due to the factors considered in the factor pattern, which indicates a sufficiently effective operation of the selected model.

The regression equation (1) was constructed based on the preliminary analysis:

$$\text{TWC (regression)} = 5.27 - 0.12*\text{VAS} + 0.03*\text{MoCA} - 0.08*\text{KI} + 0.03*\text{IAB} - 1.02*\text{NCC} \quad (1)$$

where TWC (regression) – the predicted value of the dynamics (improvement) of the time of performance of physical and cognitive tasks during three months after CC; 5.27 – standardized regression coefficient; VAS – the level of limitations of life-sustaining activity according to the VAS (points); MoCA – the general level of cognitive function (points); KI – the Kerdo index (%); IAB – the index of autonomic balance (units); NCC – the number of cerebral concussions during a sports career.

Analyzing the developed model, it can be argued that the higher the level of cognitive function in hockey players according to the MoCA test, the higher the level of the IAB (lower the level of sympathicotonia) on the third day after CC, the better the prognosis is. An increase in the level of headaches negatively affected the prognosis. The number of previous CCs in the anamnesis also negatively affected the ability to perform physical and cognitive work.

The validation of the developed regression model in practice indicated that this model predicts the results within 20 % of the existing actual values, which indicates the satisfactory operation of the developed model.

4. Discussion

The results of our work confirmed and specified the data of previous studies, which revealed significant disorders of the ANS activity during the first hours after CC in over 80.0 % of athletes [26, 27]. In particular, sympathicotonia was observed in all athletes on the first day after CC. Only 10.0 % of hockey players had normotonia on the second day, and 90.0 % had sympathicotonia ($p < 0.05$).

The research proved the greater effectiveness of the developed physical therapy program, in particular, in restoring the ability to simultaneously perform motor and cognitive tasks, compared to the existing programs [5]. In our opinion, this was the result of the use of task-specific training, when athletes performed therapeutic exercises for coordination and balance from the second day after CC (from the second day – exercises for training static balance, and from the third day – exercises for training neuromuscular control and dynamic balance were prescribed), and exercises for the development of cognitive functions with the simultaneous performance of two tasks (with physical and mental load), proprioceptive training on an unstable platform were prescribed if the SI was less. The effectiveness of this approach was proved by the dynamics of the test indicators with tandem walking and simultaneous cognitive task performance.

It is important in the work to prove the need to consider the state of the ANS, especially on the third day after CC, which was not considered by the standard SCAT 5 protocol, according to which training loads are already prescribed on this day [1, 5]. During the third visit, only 30.0 % had normotonia, and 70.0 % had sympathicotonia ($p < 0.05$), which should be considered when planning rehabilitation and training loads.

This approach became the basis for better adaptation of the mechanisms regulating the cardiovascular system, which was established by more positive dynamics of heart rate variability (the Kerdo index and the stress index of the regulatory system).

The data on the characteristic dynamics of the components of cognitive functions in the process of rehabilitation after cerebral concussion were specified in the work for the first time, in particular, it was found that the level of attention and executive functions do not change when using the SCAT 5 protocol, which requires the appointment of specific rehabilitation strategies and was implemented in the developed program [1].

The research also confirmed the data obtained in the previous study [3] on the determining negative value of the cumulative effect that occurs as a result of the accumulation of disorders in repeated CCs in professional athletes. At the same time, it was specified that a significant difference in cognitive deficit is already observed after the second case of CC in hockey players.

The data on the nature of motor dysfunction in hockey players after cerebral concussion were specified for the first time, in particular, the functions of simultaneous performance of the motor and cognitive tasks are most significantly impaired, the restoration of which is used in the work as a criterion for the effectiveness of rehabilitation measures. The work clarifies the data on the dynamics of headache level, clinical indicators of autonomic nervous system regulation, and indicators of heart rate variability. The research proved the cumulative negative impact of increasing the number of cerebral concussions received during a sports career on the level of cognitive functioning in hockey players, which coincides with the results of previous studies [28, 29, 30, 31].

The results of our research on the issue of predicting the timing of recovery after a cerebral concussion is of particular interest. The existing models took into account genetics, age, sex, and clinical, especially the severity of damage to the central nervous system after cerebral concussion [9, 10, 11]. In contrast to the existing models, the prognostic factors affecting the effectiveness of rehabilitation to restore the ability to simultaneously perform motor and cognitive tasks were identified and

quantified in the work for the first time.

5. Conclusions

The prognostic model of the effectiveness of rehabilitation for the restoration of motor and cognitive functions in hockey players after cerebral concussion was developed based on the results of the work, according to which the most significant factors aggravating the prognosis, are the level of headache according to the VAS (regression coefficient B = -0.12), the number of repeated cerebral concussions (B = -1.02), prognostically favorable factors are the general level of cognitive functions (B = 0.03), a lower level of sympathicotonia according to the autonomic balance index (B = 0.03) and the Kerdo index (B = -0.08). The developed model provides results within 20.0 % of the existing actual values, which indicates satisfactory and effective work (coefficient of determination of 54.0 %, $p < 0.05$).

The work proved the greater effectiveness of the developed physical therapy program compared to the standard one in terms of the indicators of life-sustaining activity limitations by 26.0 ± 2.1 %, the tone of the autonomic nervous system according to the Kerdo index by 9.9 ± 0.8 %, variability of heart rate according to statistical indicators of the standard deviation of cardiac intervals and variation range by 4.6 ± 0.3 % and 28.2 ± 3.5 %, respectively, according to autonomic balance index by 33.7 ± 4.9 %, decrease in SI by 22.5 ± 4.6 %, decrease in the time of tandem walking test and cognitive task by 20.1 ± 1.6 %, increase in MoCA score by 12.4 ± 2.0 % ($p < 0.05$).

Disclosure Statement

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Conflict of Interest

The authors state no conflict of interest.

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