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Original Article

Neural network modeling of diagonal stride technique of highly qualified skiers with hearing impairments

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Abstract:
Correct rational sport technique is based on models that are developed according to the kinematic characteristics of motion. According to the literature review, the questions addressed by the model are essential for studying the improvement of sport technique but the lack of those models for deaf athletes is a problem particularly in cross-country skiing. So the purpose of this research is to develop a model of the kinematic structure of classical diagonal stride technique of highly qualified cross-country skiers with hearing impairments on the basis of computer neural networks. Participants: 9 high skilled skiers with hearing impairments of the Ukrainian National Deaflympic team on skiing. Results: The modeling kinematic indicators of the diagonal stride technique of highly qualified skiers with hearing impairments have been identified. Seven neural networks of multilayer perceptron type have been developed as a simulation of the velocity of the skier's general center of mass in the movement cycle. On a basis of the best model, the errors in the diagonal stride technique of highly qualified skiers with hearing impairments were corrected. Conclusions: the neural network modeling in the process of technical performance improving of highly skilled skiers with hearing impairments is proved. Neural network modeling has allowed increasing the resultant velocity of skier's general center of mass in the cycle of motion due to accounting skier's individual biomechanical characteristics.
Key words: skier, hearing impairment, technique, modeling, neural network.

Introduction

Today, the training system of athletes with hearing impairments in such deaflympic discipline, as skiing, is based on the main provisions of the skiers' training system in Olympic sport (Khurtyk, Khmelnitska, Smirnova, 2016). It is well known that the athlete's functional state reflects integral complex of functional system which responsible for effectiveness of sports activities (Korobeynikov, Korobeinikova, Iermakov, Nosko, 2016). Therefore the athletes with hearing impairment need a special approach in training process. A number of specialists have studied the training process of skiers with hearing impairments only on the view of their physiological particuliarities, physical abilities and annual macrocycle planning. Meanwhile such important aspect of training as technical preparedness, have not been considered (Bhambhani, Forbes S., Forbes J. et al, 2012; Karlenko, Smirnova, Lymar, 2009). Recently, neural networks have come to be used for the technique simulation in various sports: swimming (Silva, Costa, Oliveira et al, 2007), high jumping (Shestakov, Averkin, 2003), javelin throwing (Maier, Wank, Bartonietz, Blickhan, 2000), shot put (Maier, Maier, Wagner, Blickhan, 2000). In cross country skiing, models of force variables have been developed using trigonometric functions and vector algebra (Pohjola, 2014). Models of ski steps, as well as models of turns allow to optimize the technique of skier's motor actions on a basis of improvement of movement biomechanical characteristics (Grasaas, Ettema, Hegge, Skovereng et al., 2014; Stoggl, Holmberg, 2016). In the A.V. Gursky's study (2012), 42 model characteristics of skilled skier's diagonal stride in the slipper step have been identified. R.A. Zubrilov (1994) developed a model of diagonal stride technique by the stepwise regression method on a base of 35 kinematic indices. Unlike regression equations, the modeling method by the neural networks is nonparametric and, therefore, more flexible. Neural networks are used in the classification tasks (Namatēvs, Aleksejeva, Poļaka, 2016), forecasting (Pettersson, Nyquist, 2017) and construction of nonlinear dependencies (Przednowek, Iskra, Wiktorowicz, Krzeszowski, Maszczyk, 2017). Application of the neural networks technology in sports disciplines with stereotyped movements enables to predict sporting results, and also significantly increases the efficiency of the training process at the expense of an individual approach, accurate biomechanical evaluation of the technique of the main motor action and the adoption of an objectively justified rational decision on its correction (Kryvetsky, Popov, 2013; Kurz, Korobeynikov, 2002; Stergiou, 2005).

Biomechanical modeling of the sports result achieving processes is an effective method of the sport technique analysis, since the correct rational technique is based on models that are developed according to the

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kinematic characteristics of motion (Stoggl, Muller, Ainegren, Holmberg, 2011). Such models allow, in particular, to correct certain elements of athlete's skiing technique (Holmberg, Lindinger, Staggl, Eitzlmair, 2005; Zubrilov, 1994).However, there are no model parameters of highly skilled hearing-impaired skiers in scientific and methodological literature. The hypothesis of this study is the following: the modeling of motor actions of highly qualified cross-country skiers with hearing deprivation in the process of technical training will increase their sport result. The purpose of the research is to develop a kinematic structural model of the classical strides for highly skilled hearing-impaired skiers on the basis of computer neural networks.

Material & methods

Participants: 9 elite skiers with hearing impairments – members of the Ukrainian National Deaflympic team on cross-country skiing. Age of athletes is from 22 to 26 years, their qualification – 1 International master of sports, 5 Ukrainian masters of sports and 3 candidates to master of sports. This study was organized in the following way: the ascertaining pedagogical experiment was conducted in February 2013 at the last stage of preparation for the World Championship in skiing among deaf athletes and reflected the initial level of their technical preparedness; the forming pedagogical experiment was conducted with the purpose to confirm the effectiveness of technology on the improving of technical actions of highly skilled hearing-impaired skiers. The duration of the forming experiment was 11 months – from May 2014 to April 2015. We used the following methods of research: analysis of scientific and methodical literature; analysis of athlete's medical record; video shooting; biomechanical video-computer analysis and neural networks modeling of the movement technique of highly skilled hearing-impaired skiers; pedagogical experiment; mathematical statistics.

The analysis of medical records of participated skiers confirmed their hearing loss at a better ear of 55 dB or more that allowed them to take part in International competitions. Video shooting of skiing was conducted in the sagittal plane by Sony camcorder with a frequency of 30 frames per second. The camcorder was installed perpendicular to the ski at a distance of 3 m at the level of the general center of mass (GCM) of athlete's body. Biomechanical analysis of videograms was conducted with the specialized software "BioVideo" that have been developed in the Department of Biomechanics, National University of Physical Education and Sport of Ukraine (Kashuba, Khmelnitska, Krupenya, 2012). The skier's technique in diagonal stride was analyzed by the following phase structure: the sliding step consisted of two periods: the period of ski slip and the period of skiing, during which the repulsion is carried out. The period of ski slip is in its turn divided into 3 phases: I phase is a free unidirectional slip on the left ski, II phase is sliding with the straightening of the support (left) leg in the knee joint, III phase is sliding with the sinking on the left foot. The period of skiing is divided into IV phase – a right leg with a sink on the left leg and a V phase – repulsion with the straightening of the pushing (left) leg.

Experimental data were processed using descriptive statistics, a nonparametric sign test, a Spearmen ranking correlation analysis. Since the general population of highly skilled hearing-impaired skiers consists of 9 athletes, that is the small sample size (n = 9), we calculated arithmetic mean ($\bar{x}$), standard deviation (S) and also the median (Me), the lower (25%) and upper (75%) quartiles. The statistical significance of the kinematic characteristics of the diagonal stride technique of highly skilled skiers with hearing impairments as a result of the pedagogical experiment was determined by means of a nonparametric criterion for dependent samples - the sign test at the level of $p = 0.05$. The statistical significance of the performance indicators in the neural networks of skier's technique is obtained at p-levels from 0.001 to 0.005. The data have been processed by Statistica Neural Networks Application (www.statsoft.com).

Results

To substantiate and determine the most informative indicators of the diagonal stride technique of highly skilled skiers with hearing impairments, the correlation analysis was performed (Table 1).

Table 1. Coefficients of correlation between the kinematic characteristics and the GCM velocity in the cycle of highly skilled cross-country skiers with hearing impairment in phases of diagonal stride, n = 9

Kinematic characteristic	Correlation coefficient
Horizontal velocity of left foot CM in the first phase of free slip on the left ski	0.95
Horizontal velocity of left foot CM in the second phase of sliding with straightening in the knee	0.94
Duration of the second phase of sliding with straightening in the knee joint	0.73
Vertical velocity of the athlete's GCM in the second phase of slipping with straightening in the knee joint	0.78
Vertical velocity of right hand CM (ski pole)	0.88
Duration of ski standing period	0.68
Angle of right elbow joint at the moment of setting the right pole on the snow	0.49
Resultant velocity of right forearm CM in the fifth phase of repulsion with straightening of the pushed leg	-0.75
Angle of left knee joint at the moment of left ski stopping	-0.81
Angle of right hip joint at the beginning of left leg extension in the knee joint	0.81
Angle of right hip joint at the moment of take off left ski from the snow	0.81
Angle of left ankle joint at the moment of take off right ski from the snow	-0.80

Note. Correlation coefficients are significant at the level of $p < 0.05$ (the critical value $r_{9;0,05} = 0.67$).

The method of neural network was selected for modeling, because one allowed reproducing the dependencies when the exact type of connections between the inputs and outputs was unknown. If it were known, then the connection could be directly simulated. One of the major advantages of neural networks is that they are capable of approximating any continuous function, and thus the researcher does not need to have any hypotheses about the underlying model, or even which variables matter. Another essential feature of a neural network is that the relationship between input and output is identified in the process of the neural network learning. For the neural network training, we have formed a set of training data – a training sample – the kinematics of technical actions of 9 highly skilled skiers. Those data were obtained as a result of the ascertaining experiment at the last stage of preparation for the World Championship in cross-country skiing among deaf athletes. We processed 54 videograms (4 videograms per everyone of 9 skiers). The neural network learned to establish a relationship between inputs and target on the training data set (input data and their corresponding outputs, that is, the sport result – the velocity of highly skilled hearing-impaired skiers in the cycle). To testify the training quality, that is, the model adequacy, is necessary on verification data set that was not used in a neural network training. We selected kinematic indicators of skiing technique, which have been obtained from the results of biomechanical video analysis of 36 videograms of 9 highly skilled skiers' performances at the Ukrainian Championship on cross-country skiing among deaf athletes, which took place at the beginning of the competition period in preparation for Winter Deaflympic Games 2015 (4 videograms per everyone of 9 skiers). Those data were divided into verification and test sets in equal parts (per 18 videograms). Verification set was used for model validation. As a result of neural network building, we received seven neural networks (Table 2), which had a MultiLayer Perceptron (MLP) architecture. An optimal model is a neural network that produces a minimum test error that is the neural network number 5 MLP 31-23-1. Then we finally checked performance of this best network No. 5 MLP 31-23-1 performance against the independent test set.

Table 2. Neural networks of diagonal stride technique of highly qualified cross-country skiers with hearing impairments

No.	Neural Network Architecture	Training Efficiency	Test Efficiency	Efficiency reliability	Training error	Test error	Significance of error
1	MLP 31-11-1	0.9210	0.3457	0.9859	0.0015	0.0068	0.0035
2	MLP 31-13-1	0.9245	0.4016	0.9910	0.0025	0.0051	0.0045
3	MLP 31-20-1	0.9170	0.4425	0.9905	0.0036	0.0049	0.0047
4	MLP 31-7-1	0.9300	0.4100	0.9905	0.0023	0.0051	0.0040
5	**MLP 31-23-1**	**0.9076**	**0.5068**	**0.9909**	**0.0015**	**0.0048**	**0.0024**
6	MLP 31-8-1	0.9276	0.4122	0.9858	0.0019	0.0055	0.0035
7	MLP 31-22-1	0.9250	0.4088	0.9873	0.0019	0.0057	0.0033

Note. The first digit in the name of the neural network – 31– shows the amount of input data (kinematic characteristics of the skier's diagonal stride technique). The second digit indicates the number of hidden network layers. The third digit – the output variable – the velocity of the skier's body GMC in a cycle of diagonal stride.

An important result is an analysis of the neural network sensitivity, which shows how strongly the input variables (kinematic characteristics of double stride) influence on the output that is the resultant velocity of the highly skilled skier with hearing impairments in the cycle (see Table 3). The contribution of the indicator "the vertical velocity of right hand CM (ski pole) in the second phase" is the largest value that is 1.237.

Table 3. Indicators of the sensitivity analysis that shows how the parameters of the diagonal stride technique influence on the GCM velocity of highly skilled skier with hearing impairments in the motion cycle

Indicator	Neural Network				
	No. 5 MPL 31-23-1	No. 1 MPL 31-11-1	No. 2 MPL 31-13-1	No. 3 MPL 31-20-1	No. 4 MPL 31-7-1
Vertical velocity of right hand CM (ski pole) in phase II	1.237	1.143	1.183	1.140	1.241
Duration of phase II	1.134	1.123	1.110	1.096	1.147
The resultant velocity of right forearm CM in the phase V	1.115	1.086	1.085	1.108	1.107
Angle of left ankle joint at the moment of take off the right ski from the snow	1.084	1.055	1.048	1.062	1.070
Angle of right hip at the moment of take off the left ski from the snow	1.070	1.036	1.036	1.056	1.062
Horizontal velocity of left foot CM in the phase II	1.036	1.029	1.033	1.027	1.025

We developed the complexes of physical exercises in order to correct the errors in the technical actions of highly skilled skiers with hearing deprivation in diagonal stride technique on the basis of the obtained model characteristics of the neural network number 5 MLP 31-23-1. Positive increasing in sports results of the Ukrainian Deaflympic team on cross-country skiing indicates the effectiveness of the neural network modeling in the improving their technical actions at the stages of the annual cycle (Table 4).

Table 4. Biomechanical characteristics of the diagonal stride technique of highly skilled cross-country skiers with hearing impairment before and after the experiment, n = 9

Indicator	The beginning of experiment		The end of experiment		Neural network model (max value)	
	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S
Resultant velocity of right forearm CM in phase V	5.32	0.91	5.88*	1.12	6.54	0.89
Horizontal velocity of left foot CM in phase II	6.11	0.35	6.78*	0.65	7.25	0.78
Angle of right hip at the moment of take off left ski from the snow	112.1	7.06	115.6*	5.34	122.00	6.12
Angle of left ankle joint at the moment of take off right ski from the snow	112.8	7.45	128.7*	6.05	139.00	6.13
Vertical velocity of right hand CM (ski pole) in phase II	1.76	0.23	2.13*	0.2 5	2.21	0.28
Duration of phase II	0.20	0.02	0.22	0.02	0.25	0.03

Note. * - the difference between the indicators as a result of the pedagogical experiment is statistically significant at the level p <0.05.

In each competitive programs of the World Championship and Winter Deaflympic 2015, participants of the experiment – everyone of 9 skiers – decreased the losing time against the winner from 85.82 to 59.76 s (p <0.05) and increased their average sport result according to the amount of prized places from 4.5 to 3.3 places (p<0.05). At the same time, the skier's individual dynamics of these indicators testifies about their predominant growth.

Discussion

As a result of the experiment, biomechanical characteristics of the diagonal stride technique of highly qualified skiers with hearing impairments were received firstly. The results of our study on the leading biomechanical characteristics of the diagonal stride technique are consistent with the data of the authors (Gursky, 2013; Kolikhmatov, Golovachev, Shirokova, 2015; Zubrilov, 1994). The analysis of each separate phase duration in the diagonal stride technique of highly qualified skiers with hearing deprivation indicates their lagging behind healthy skilled skiers (Table 5).

Table 5. Phase duration of the diagonal stride technique of highly qualified cross-country skiers with hearing impairments against healthy cross-country skiers

Phase	Phase duration, s				
	Cross-country skiers with hearing impairments			Healthy cross-country skiers	
	Khurtyk, 2016			Gursky, 2014	Kolikhmatov, 2015
	$\bar{x}$	S	Me (25 %, 75 %)	$\bar{x}$	$\bar{x}$
I	0.17	0.04	0.17 (013; 0.17)	0.09	0.13
II	0.20	0.02	0.20 (0.19; 0.2)	0.19	0.18
III	0.09	0.01	0.09 (0.09; 0.10)	0.06	0.05
IV	0.09	0.02	0.09 (0.07; 0.01)	0.03	0.03
V	0.10	0.02	0.10 (0.09; 0.10)	0.09	0.08

The velocity in movement cycle of highly skilled skiers with hearing impairments is 6.98 $m\cdot s^{-1}$; that is lower comparing to the velocity of healthy skiers – 7.3 $m\cdot s^{-1}$ (Kolikhmatov, Golovachev, Shirokova, 2015), 6.71 $m\cdot s^{-1}$ (Pohjola, 2014), but higher than one in cross-country sit skiers – 4.61 $m\cdot s^{-1}$ (Rosso, Gastaldi, Rapp, Lindinger, Vanlandewijck, Linnamo, 2016).

A neural networks modeling of diagonal stride technique in skiing was used for the first time. R.A. Zubrilov built the velocity model (from 4,07 to 4,83 $m\cdot s^{-1}$) for highly skilled female skier's diagonal stride. This model in the form of a regression equation includes 9 variables, which are based on the coordinates of 18 points – the athlete's body centers of the joints. The model explains 86% dispersion of the velocity in a cycle and has an error of 1.8% (Zubrilov, 1994). Comparing with this model, our model includes 6 variables, therefore, it is simpler in terms of practical implementation. By increasing the number of hidden layers and the number of neurons in them, you can provide any accuracy of the neural network. The neural network model developed by us has been trained for each skier with hearing impairments on the basis of the indicators of 20 points – the joint's centers, as well as the indices of the athlete's body segment CM. Therefore the neural network model is more accurate. Model error does not exceed 1%. Consequently, the significant advantages of neural network modeling in comparison with the regression analysis are the following: less volume of necessary computations and greater accuracy. The GCM velocity of skiers with hearing impairments in the cycle increased from 6.58 to 7.16 $m\cdot s^{-1}$; the vertical velocity of right hand CM (ski pole) in the moment of placing on the snow increased by

0.37 m· s^{-1} significantly statistically ($p < 0.05$) as a result of the experiment. So the forecasting of athlete's motor actions, taking into account his individual characteristics, optimizes the real training process (Holmberg, Lindinger, Staggl, Eitzlmair, 2005; Kashuba, Khmelnitska, Krupenya, 2012; Zhanneta, et al., 2015).

Conclusions

Analysis of scientific and methodological literature shows that the use of the neural network to simulate the process of the diagonal stride technique improving for highly qualified cross-country the diagonal stride technique the diagonal stride technique skiers with hearing impairments is one of the topical issues in Deaflympic sport.

As a result of the experiment, a neural network model of a MultiLayer Perceptron MPL 31-23-1 architecture was built. One was explored to correct the kinematic parameters of the diagonal stride technique of highly skilled cross-country skiers with hearing deprivation that has allowed increasing the skier's GCM resultant velocity in a motion cycle.

Prospects for further research are to build the neural network models of athlete's technical actions in other Deaflympic sports.

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