Research article

QUALITATIVE AND QUANTITATIVE EVALUATION OF THE CHARACTERISTICS OF THE ISOMETRIC MUSCLE FORCE OF DIFFERENT MUSCLE GROUPS IN CADET JUDO ATHLETES: A GENDER-BASED MULTIDIMENSIONAL MODEL

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Abstract. *The aim of this paper is to define the initial quantitative and qualitative multidimensional model for evaluating basic contractile characteristics of isometric muscle force in systematically trained and selected cadet judo athletes. In this research absolute values of the obtained results, and values derived by relativization of absolute values in relation to skeletal muscle mass (SMM) were considered. The basic method used in this research was laboratory testing. All data sampling was performed by the dynamometry method, using tensiometric probes. The research sample in this study consisted of 21 cadet judo athletes, of which 14 were male and 7 were female. All measurements were performed using standardized testing procedures on the following muscle groups: flexor muscles of the left (HGL) and the right hand (HGR), back (DL) and leg extensor muscles (LE) and ankle joint plantar flexor muscles (PF). Based on the obtained results, separate multidimensional mathematical models for the estimation of contractile potential and development level were defined for both basic characteristics of isometric muscle force: maximal isometric muscle force (F_{max}) and maximal explosive isometric muscle force (RFD_{max}). A qualitative assessment of contractile potential for each of the tested muscle groups, i.e. variables, was enabled by defining standard values for 7 distinct preparedness levels for both basic isometric muscle force contractile characteristics of male and female cadet judo athletes.*

Key words: *judo, cadets, isometric muscle force, standard values, model*

INTRODUCTION

Judo is an Olympic martial sport that can be classified as a polystructural, acyclic sport discipline in which highly intensive intermittent work is dominant (Franchini, Del Vecchio, Matsushigue, & Artioli, 2011). This is a dynamic, physically demanding sport, in which a high level performance requires complex motor skills and achieved tactical excellence (Cuk, Bratić, & Mučibabić, 2016; Thomas, Cox, LeGal, Verde, & Smith, 1989). From a physiological point of view, anaerobic power and capacity, as well as all the characteristics of muscle force and power, can be considered the main physical characteristics to be developed in judo competitors (Thomas et al., 1989) in order to achieve the necessary preconditions for achieving top results. A direct victory over an opponent in judo sport is primarily accomplished by the successful application of the throwing technique in a standing position, or by application of joint lock techniques or immobilizations in groundwork combat (Saraiva, Reis, Costa, Bentes, Costa e Silva, & Novaes, 2014). Accordingly, the basic effort of the competitor during a judo contest is to throw the opponent on his back or control him on the ground (Franchini, Nunes, Moraes, & Del Vecchio, 2007).

During a judo fight, the greatest number of explosive actions occur when an athlete attempts to defeat his/her opponent by rapid utilization of isolated or chained offensive actions or maneuvers (Monteiro, Chambel, & Cardoso, 2011). The very use of the judo throwing technique depends on a number of preparatory elements, all aimed to achieving preconditions for unobstructed application of the throw. This can be accomplished through an effectively planed and implemented grip fighting (kumikata) which consumes about 50% of the active fighting time (Calmet, Miarka, & Franchini, 2010; Marcon, Franchini, Jardim, & Barros Neto, 2010). Such an approach allows judo athletes to off-balance the opponent thus creating an opportunity for the execution of the throw which itself requires rapid actions (typically shorter than 1s) engaging upper and lower body muscle groups (Marcon et al., 2010; Blais, Trilles, & Lacouture, 2007). In general, it can be said that for the efficient utilization of technique, it is necessary to apply it in the right manner, i.e. utilize it in the right moment, with a sufficient amount of strength and speed (Stamenković, Stanković, Nurkić, Nikolić, & Petković, 2016).

Previous research indicates that approximately 70% of all injuries sustained in judo are a consequence of the throwing technique application (Pocecco et al., 2013) which further implies an irrefutable and crucial significance of this element in judo fighting, both in the context of sports achievement and in the context of sports preparation. Taking into account the complex nature of the judo sport (Milišić, 2003), as well as the fact that judo athletes overcome a significant external resistance in the form of actively resisting opponent, it is clear that achieving an adequate level of development of contractile characteristics of the involved musculature, both from the aspect of force (i.e. strength) and from the aspect of power, is one of the key elements that must be developed through a systematic training progression. This is in relation with the fact that muscular strength and power are considered the most highly ranked in the hierarchy of training abilities in successful judoka (Nurkić, Bratić, Mitić, Kafentarakis, 2017), and with the previous findings that indicate the utmost importance of muscle force and power training as a basic factor contributing to successful competitive performance both in judo and other martial sports (Detanico, Budal Arins, Dal Pupo, & Dos Santos, 2012; Franchini, Del Vecchio, Matsushigue, & Artioli, 2011; Laskowski & Suchanowski, 2010; Thomas, Cox, LeGal, Verde, & Smith, 1989).

Based on the afore mentioned, a general conclusion can be drawn that the long-term preparation of an athlete in judo sport requires development of, at least, an adequate level of maximal muscle force of all the basic muscle groups. This can be considered a precondition for expressing a high level of the given contractile characteristic necessary for successful competition performance, as well as a foundation element contributing to injury prevention. However, recent research (Monteiro, 2016; Monteiro et al., 2011) indicates that a factor of key importance for achieving top results in judo can be the manifestation of a high level of development of explosive muscle force, i.e. explosiveness (RFD – rate of force development), which influences the effective execution of technique and the application of defensive maneuvers during the match.

According to the applicable rules of the International Judo Federation (IJF), competitors in judo are divided into 3 distinct age categories (cadets, juniors and seniors) in relation to chronological age (Sport and organization rules of the international judo federation, ed. 2017). This division is in compliance with the scientifically based concept of long-term sports career planning in which cadet age is considered initial in the system of sport selection and preparation (Koprivica, 2013; Dopsaj, 2015). Taking into account the afore mentioned and considering the fact that Umbrella sports organizations in judo sport, the European Judo Union (EJU) and the International Judo Federation (IJF), equally promote competitions for male and female competitors (Sindik, Rendulić, Čorak, & Lewis, 2014), it is necessary to provide a system for the evaluation of basic contractile characteristics of muscle force at this initial age, as well as through the entire career progression, for both male and female competitors.

In accordance to the previous, this paper presents one of the initial studies aimed at defining the quantitative multidimensional model as well as the initial qualitative standard values in function of prediction and estimation of preparedness levels for both basic characteristics of isometric muscle force (F_{max} and RFD_{max}) in systematically trained and selected cadet judo athletes, both considering absolute values of the obtained results and values derived by relativization of absolute values in relation to skeletal muscle mass (SMM). Partialization of the results was enabled by the application of a new methodology for measuring the body structure of the participants using the InBody 720 system, which operates on the measurement principle of multichannel multisegmental bioelectric impedance (Dopsaj et al., 2015).

In this manner, relevant information is obtained, further increasing the body of scientific knowledge in this area and providing practical means for objective monitoring and improvement of the training process and long-term preparation in judo sport.

METHODS

The method used in this research was laboratory testing. All data sampling was performed by a dynamometry method, using tensiometric probes.

The research sample

The research sample in this study consisted of 21 cadet judo athletes, of which 14 were male and 7 were female. The basic descriptive characteristics for the male judo athlete sub-sample were: Age = 15.80 ± 0.96 years, BH = 174.25 ± 5.38 cm, BM = 66.71 ± 6.01 kg, BMI

= 22.03 ± 2.44 kg·m^{-2}, SMM = 35.48 ± 3.57 kg, PSMM% = 53.23 ± 3.05 %, Training Experience = 4.06 ± 2.24 years, Weekly Training Frequency = 4.00 ± 0.50 sessions per week, Weekly Training Volume = 420.00 ± 30.00 minutes. The basic descriptive characteristics for the female judo athlete sub-sample were: Age = 16.90 ± 0.57 years, BH = 159.87 ± 7.79 cm, BM = 59.05 ± 12.50 kg, BMI = 22.91 ± 3.34 kg·m^{-2}, SMM = 26.37 ± 3.84 kg, PSMM% = 45.38 ± 5.45 %, Training Experience = 6.08 ± 3.56 years, Weekly Training Frequency = 4.00 ± 0.50 sessions per week, Weekly Training Volume = 410.00 ± 25.00 minutes.

All of the participants were competing in the national championship system of the Republic of Serbia for the cadet age category. Two of the participants (one male and one female) were members of the Serbian cadet national team.

Measurement protocols

Before the beginning of this research, parents of all the participants (they were under the age of 18) read and signed an informed consent form. All of the participants and their coaches were informed in detail about the measurement procedures and the possible risks and benefits of this research. The study was approved by the Ethics Committee of the Faculty of Sport and Physical Education of the University of Belgrade. Testing of muscle force characteristics was performed using a dynamometry method, by application of isometric tensiometry, by means of tensiometric probes (Isometrics SMS All4Gym, Belgrade). All tests were performed at the University of Belgrade Faculty of Sport and Physical Education in the Methodological research laboratory (MIL). All tests were carried out in the morning hours by the application of a standardized testing procedure and standardized test battery described in previously published literature (Dopsaj, Milošević, Blagojević, 2000; Dopsaj et al., 2007; Marković, Dopsaj, & Jovanović, 2017). For the purpose of avoiding negative effects of acute fatigue, all tested participants were not involved in any major physical activity 24 hours prior to the testing. Specific testing positions for each of the applied isometric muscle force tests are shown in pictures 1 − 4.

Before the beginning of the testing, all of the participants performed 10 min of individual warm-up. After that the testing was carried out. The testing procedure required an explanation of the way each test is performed. Each participant had two trial attempts performed at high and submaximal intensity for the purpose of familiarization with the testing procedure. After having at least a 5 min rest, the testing was carried out using the trial-to-trial method, where the break between testing attempts was a minimum of 2 min. Better test results were taken for statistical processing (Ivanović & Dopsaj, 2013).

Variables

For the purposes of this paper, contractile characteristics of the isometric muscle force were examined from the aspect of the maximal level of its manifestation (F_{max}) and from the aspect of the maximal level of intensity of its manifestation (RFD_{max}). In other words, maximal isometric muscle force (F_{max}) and maximal explosive muscle force (RFD_{max}) characteristics were examined.

Fig. 1 Isometric Plantar Flexion, seated position

Fig. 2 Isometric Dead Lift

Fig. 3 Isometric Leg Extension, standing

Fig. 4 Isometric Hand Grip, seated position

All tests were performed on 5 muscle groups as follows: flexor muscles of the left (HGL) and the right hand (HGR), back (DL) and leg (LE) extensor muscles and ankle joint plantar flexor muscles (PF).

The following variables were used for the measurement of maximal isometric muscle force:

- HGL_F_{max} − maximal isometric force of the flexor muscles of the left hand expressed in N;
- HGR_F_{max} − maximal isometric force of the flexor muscles of the right hand expressed in N;

- DL_F_{max}, maximal isometric force of back extensor muscles expressed in N;
- LE_F_{max}, maximal isometric force of leg extensor muscles expressed in N;
- PF_F_{max}, maximal isometric force of ankle joint plantar flexors expressed in N;

The following variables were used for measurement of maximal explosive isometric muscle force (explosiveness):

- HGL_RFD_{max} – maximal explosive isometric muscle force of the flexor muscles of the left hand expressed in $N \cdot s^{-1}$;
- HGR_RFD_{max} – maximal explosive isometric muscle force of the flexor muscles of the right hand expressed in $N \cdot s^{-1}$;
- DL_RFD_{max}, maximal explosive isometric muscle force of back extensor muscles expressed in $N \cdot s^{-1}$;
- LE_RFD_{max}, maximal explosive isometric muscle force of leg extensor muscles expressed in $N \cdot s^{-1}$;
- PF_RFD_{max}, maximal explosive isometric muscle force of ankle joint plantar flexors expressed in $N \cdot s^{-1}$;

All absolute values of the examined variables were partialized relative to pure skeletal muscle mass (SMM) in order to obtain relevant data in relation to the used component of the body which is directly responsible for the manifestation of the contractile potential of skeletal muscles. All calculations were done using the standard calculation formula as follows: VAR_CC_{rel} = VAR_CC_{max} / SMM, where VAR_CC_{max} represents the measured value of the isometric muscle force characteristic for the given muscle group, SMM represents skeletal muscle mass expressed in kg, while VAR_CC_{rel} represents the value of the variable derived.

Statistical analysis

For the purposes of this paper, in the first step of the analysis all raw data obtained by laboratory testing were subjected to descriptive statistical analysis in order to define the basic measure of central tendency (MEAN), indicators of data dispersion - standard deviation and coefficient of variation (SD, cV%) and result span indicators – minimum and maximum (MIN, MAX). Normality of the distribution of the results was estimated for each variable by application of the Shapiro-Wilk test. Based on the obtained results, for each of the tested muscle groups, i.e. variables, the initial qualitative standard values were defined using adequate sport metrological procedures (Зациорски, 1982). In the next step of analysis, mathematical modeling by means of multidimensional scaling was used to define the total numerical score of general fitness in function of each measured contractile characteristic (Dopsaj et al., 2010; Dopsaj, 2015). In this way general preparedness for both maximal isometric muscle force (Bod_SCORE_F_{max}) and maximal isometric explosive muscle force (Bod_SCORE_RFD_{max}) was presented by mathematical analogy where the value of test score for each individual participant was transformed into a proportional point score on a scale from 0 (hypothetical minimum) to 100 (hypothetical maximum) points. The final form of the mathematical model was defined by application of the Multivariate Regression Analysis (MRA), where the value of point score represented the criterion variable, and the results of 5 isometric tests represented a system of predictor variables. All analysis were conducted by use of statistical packages Microsoft Office Excel 2013 and IBM SPSS v23.0.

RESULTS

The results of descriptive statistical analysis relative to the examined absolute and relative variables of maximal isometric muscle force (F_{max}) with the results of the Shapiro-Wilk goodness of fit test, for both male and female judo athletes, are shown in Table 1.

Table 1 Descriptive statistics for the maximal isometric muscle force (F_{max}) variables with the results of the Shapiro-Wilk normality test

	N	MEAN	SD	%cV	MIN	MAX	S-W	p
Male Judo Athletes								
Absolute values								
HGL_F_{max} (N)	14	427.23	97.04	22.71	281.00	558.00	0.905	0.133
HGR_F_{max} (N)	14	448.92	100.58	22.40	305.00	641.00	0.965	0.804
DL_F_{max} (N)	14	1264.62	299.25	23.66	845.00	1779.00	0.952	0.594
LE_F_{max} (N)	14	1151.54	254.22	22.08	723.00	1628.00	0.990	1.000
PF_F_{max} (N)	14	3177.54	786.16	24.74	2228.00	4957.00	0.877	0.053
Relative values								
HGL_F_{rel} (N·kg$_{SMM}^{-1}$)	14	12.00	2.29	19.06	8.17	15.87	0.965	0.806
HGR_F_{rel} (N·kg$_{SMM}^{-1}$)	14	12.57	2.10	16.72	9.76	16.52	0.939	0.405
DL_F_{rel} (N·kg$_{SMM}^{-1}$)	14	35.42	6.52	18.39	24.56	47.06	0.970	0.881
LE_F_{rel} (N·kg$_{SMM}^{-1}$)	14	32.25	5.20	16.12	22.88	43.07	0.924	0.249
PF_F_{rel} (N·kg$_{SMM}^{-1}$)	14	89.58	20.70	23.10	72.45	134.70	0.768	0.002
Female Judo Athletes								
Absolute values								
HGL_F_{max} (N)	7	240.83	64.70	26.86	182.00	348.00	0.852	0.128
HGR_F_{max} (N)	7	241.83	47.61	19.69	195.00	333.00	0.889	0.272
DL_F_{max} (N)	7	714.50	76.04	10.64	612.00	844.00	0.965	0.859
LE_F_{max} (N)	7	634.00	99.29	15.66	530.00	779.00	0.887	0.259
PF_F_{max} (N)	7	2917.17	572.43	19.62	2435.00	4000.00	0.844	0.107
Relative values								
HGL_F_{rel} (N·kg$_{SMM}^{-1}$)	7	9.22	2.33	25.26	6.04	12.30	0.954	0.764
HGR_F_{rel} (N·kg$_{SMM}^{-1}$)	7	9.35	2.21	23.70	6.19	12.51	0.956	0.788
DL_F_{rel} (N·kg$_{SMM}^{-1}$)	7	27.41	3.41	12.43	21.80	32.26	0.982	0.969
LE_F_{rel} (N·kg$_{SMM}^{-1}$)	7	24.47	4.82	19.71	16.56	31.11	0.972	0.912
PF_F_{rel} (N·kg$_{SMM}^{-1}$)	7	111.71	20.86	18.68	82.51	143.88	0.991	0.995

The results of the descriptive statistical analysis relative to the examined absolute and relative variables of maximal explosive isometric muscle force (RFD_{max}), with the results of the Shapiro-Wilk goodness of fit test, for both male and female judo athletes, are shown in Table 2.

Table 2 Descriptive statistics for the maximal isometric explosive muscle force (RFD_{max}) variables with the results of the Shapiro-Wilk normality test

	N	MEAN	SD	%cV	MIN	MAX	S-W	p
Male Judo Athletes								
Absolute values								
HGL_RFD_{max} (N·s^{-1})	14	2614.85	740.27	28.31	1776	3748	0.881	0.060
HGR_RFD_{max} (N·s^{-1})	14	2658.85	795.60	29.92	1779	4261	0.900	0.112
DL_RFD_{max} (N·s^{-1})	14	6697.69	2810.77	41.97	3673	13679	0.878	0.054
LE_RFD_{max} (N·s^{-1})	14	4852.23	1238.52	25.52	3329	7425	0.920	0.221
PF_RFD_{max} (N·s^{-1})	14	14252.08	3634.04	25.50	9819	22557	0.918	0.205
Relative values								
HGL_RFD_{rel} (N/s$^{-1kgSMM}$)	14	73.59	19.61	26.64	52.67	108.12	0.881	0.060
HGR_RFD_{rel} (N/s$^{-1kgSMM}$)	14	74.80	20.86	27.89	53.08	125.69	0.885	0.069
DL_RFD_{rel} (N/s$^{-1kgSMM}$)	14	186.70	64.24	34.52	97.17	312.52	0.927	0.276
LE_RFD_{rel} (N/s$^{-1kgSMM}$)	14	136.52	30.65	22.45	88.07	201.22	0.967	0.831
PF_RFD_{rel} (N/s$^{-1kgSMM}$)	14	402.60	99.41	24.69	295.66	612.96	0.847	0.020
Female Judo Athletes								
Absolute values								
HGL_RFD_{max} (N·s^{-1})	7	1651.33	717.22	43.43	953.00	2697.00	0.876	0.209
HGR_RFD_{max} (N·s^{-1})	7	1633.00	554.26	33.94	1123.00	2650.00	0.885	0.251
DL_RFD_{max} (N·s^{-1})	7	4038.67	1446.81	35.82	2358.00	6408.00	0.936	0.599
LE_RFD_{max} (N·s^{-1})	7	3466.00	1489.33	42.97	1999.00	6290.00	0.896	0.308
PF_RFD_{max} (N·s^{-1})	7	13026.67	5352.60	41.09	5738.00	21376.00	0.957	0.793
Relative values								
HGL_RFD_{rel} (N/s$^{-1kgSMM}$)	7	63.78	27.49	43.10	29.50	95.30	0.878	0.217
HGR_RFD_{rel} (N/s$^{-1kgSMM}$)	7	62.60	20.39	32.57	39.47	93.64	0.934	0.588
DL_RFD_{rel} (N/s$^{-1kgSMM}$)	7	152.95	47.30	30.92	87.59	226.43	0.975	0.934
LE_RFD_{rel} (N/s$^{-1kgSMM}$)	7	133.13	53.41	40.11	61.89	222.26	0.973	0.920
PF_RFD_{rel} (N/s$^{-1kgSMM}$)	7	495.44	189.98	38.35	221.54	768.92	0.977	0.941

Table 3 shows the initial reference values of the contractile characteristic F_{max}, i.e. maximal isometric muscle force, defined for each of the tested muscle groups in absolute and relative values for both male and female judo athletes.

Table 3 Qualitative standard values for evaluating maximal isometric muscle force (F_{max})

Male Judo Athletes					
Absolute values					
MARK		HGL_F_{max} (N)	HGR_F_{max} (N)	DL_F_{max} (N)	LE_F_{max} (N)	PF_F_{max} (N)
Superior	7	>621	>650	>1863	>1660	>4750
Excellent	6	524-621	551-650	1565-1863	1407-1660	3965-4750
Good	5	477-524	500-550	1415-1564	1280-1406	3572-3964
Average	4	380-476	400-499	1116-1414	1025-1279	2785-3571
Satisfying	3	331-379	349-399	966-1115	898-1024	2392-2784
Not satisfying	2	233-330	248-348	667-965	643-897	1605-2391
Bad	1	<233	<248	<666	<643	<1605
Relative values					
MARK		HGL_F_{rel} ($N \cdot kg_{SMM}^{-1}$)	HGR_F_{rel} ($N \cdot kg_{SMM}^{-1}$)	DL_F_{rel} ($N \cdot kg_{SMM}^{-1}$)	LE_F_{rel} ($N \cdot kg_{SMM}^{-1}$)	PF_F_{rel} ($N \cdot kg_{SMM}^{-1}$)
Superior	7	>16.57	>16.78	>48.45	>42.64	>130.97
Excellent	6	14.30-16.57	14.69-16.78	41.95-48.45	37.45-42.64	110.28-130.97
Good	5	13.15-14.29	13.64-14.68	38.69-41.94	34.85-37.44	99.94-110.27
Average	4	10.87-13.14	11.53-13.63	32.17-38.68	29.66-34.84	79.24-99.93
Satisfying	3	9.72-10.86	10.48-11.52	28.92-32.16	27.06-29.65	68.89-79.23
Not satisfying	2	7.42-9.71	8.37-10.47	22.39-28.91	21.85-27.05	48.19-68.88
Bad	1	<7.42	<8.37	<22.39	<21.85	<48.19
Female Judo Athletes					
Absolute values					
MARK		HGL_F_{max} (N)	HGR_F_{max} (N)	DL_F_{max} (N)	LE_F_{max} (N)	PF_F_{max} (N)
Superior	7	>370	>337	>867	>833	>4062
Excellent	6	307-370	290-337	792-867	734-833	3491-4062
Good	5	274-306	267-289	754-791	685-733	3204-3490
Average	4	209-273	219-266	677-753	585-684	2632-3203
Satisfying	3	177-208	195-218	639-676	536-584	2346-2631
Not satisfying	2	111-176	147-194	562-638	435-535	1772-2345
Bad	1	<111	<147	<562	<435	<1772
Relative values					
MARK		HGL_F_{rel} ($N \cdot kg_{SMM}^{-1}$)	HGR_F_{rel} ($N \cdot kg_{SMM}^{-1}$)	DL_F_{rel} ($N \cdot kg_{SMM}^{-1}$)	LE_F_{rel} ($N \cdot kg_{SMM}^{-1}$)	PF_F_{rel} ($N \cdot kg_{SMM}^{-1}$)
Superior	7	>13.89	>13.78	>34.23	>34.11	>153.43
Excellent	6	11.57-13.89	11.57-13.78	30.83-34.23	29.30-34.11	132.58-153.43
Good	5	10.40-11.56	10.46-11.56	29.13-30.82	26.89-29.29	122.15-132.57
Average	4	8.07-10.39	8.25-10.45	25.72-29.12	22.07-26.88	101.29-122.14
Satisfying	3	6.90-8.06	7.14-8.24	24.02-25.71	19.65-22.06	90.85-101.28
Not satisfying	2	4.56-6.89	4.92-7.13	20.60-24.01	14.82-19.64	69.98-90.84
Bad	1	<4.56	<4.92	<20.60	<14.82	<69.98

Table 4 shows the initial reference values of the contractile characteristic RFD_{max}, i.e. maximal explosive isometric muscle force (explosiveness), defined for each of the tested muscle groups in absolute and relative values for both male and female judo athletes.

Table 4 Qualitative standard values for evaluating maximal isometric explosive muscle force (RFD_{max})

Male Judo Athletes					
Absolute values					
MARK		HGL_RFD_{max} (N·s^{-1})	HGR_RFD_{max} (N·s^{-1})	DL_RFD_{max} (N·s^{-1})	LE_RFD_{max} (N·s^{-1})	PF_RFD_{max} (N·s^{-1})
Superior	7	>4095	>4250	>12319	>7329	>21520
Excellent	6	3356-4095	3455-4250	9509-12319	6092-7329	17887-21520
Good	5	2986-3355	3058-3454	8104-9508	5472-6091	16070-17886
Average	4	2246-2985	2262-3057	5293-8103	4234-5471	12436-16069
Satisfying	3	1876-2245	1864-2261	3888-5292	3615-4233	10619-12435
Not satisfying	2	1134-1875	1068-1863	1077-3887	2375-3614	6984-10618
Bad	1	<1134	<1068	<1076	<2375	<6984
Relative values					
MARK		HGL RFD_{rel} (N/s$^{-1kgSMM}$)	HGR RFD_{rel} (N/s$^{-1kgSMM}$)	DL RFD_{rel} (N/s$^{-1kgSMM}$)	LE RFD_{rel} (N/s$^{-1kgSMM}$)	PF RFD_{rel} (N/s$^{-1kgSMM}$)
Superior	7	>112.81	>116.52	>314.54	>197.83	>601.41
Excellent	6	93.21-112.81	95.67-116.52	250.32-314.54	167.19-197.83	502.02-601.41
Good	5	83.41-93.20	85.24-95.66	218.20-250.31	151.86-167.18	452.31-502.01
Average	4	63.80-83.40	64.38-85.23	153.96-218.19	121.21-151.85	352.91-452.30
Satisfying	3	53.99-63.79	53.95-64.37	121.84-153.95	105.88-121.20	303.20-352.90
Not satisfying	2	34.38-53.98	33.08-53.94	57.60-121.83	75.22-105.87	203.78-303.19
Bad	1	<34.38	<33.08	<57.60	<75.22	<203.78
Female Judo Athletes					
Absolute values					
MARK		HGL_RFD_{max} (N·s^{-1})	HGR_RFD_{max} (N·s^{-1})	DL_RFD_{max} (N·s^{-1})	LE_RFD_{max} (N·s^{-1})	PF_RFD_{max} (N·s^{-1})
Superior	7	>3086	>2142	>6932	>6445	>23732
Excellent	6	2370-3086	2188-2742	5486-6932	4956-6445	18380-23732
Good	5	2011-2369	1911-2187	4763-5485	4212-4955	15704-18379
Average	4	1294-2010	1357-1910	3316-4762	2722-4211	10351-15703
Satisfying	3	935-1293	1080-1356	2593-3315	1988-2721	7675-10350
Not satisfying	2	217-934	524-1079	1145-2592	487-1977	2321-7674
Bad	1	<217	<524	<1145	<487	<2321
Relative values					
MARK		HGL RFD_{rel} (N/s$^{-1kgSMM}$)	HGR RFD_{rel} (N/s$^{-1kgSMM}$)	DL RFD_{rel} (N/s$^{-1kgSMM}$)	LE RFD_{rel} (N/s$^{-1kgSMM}$)	PF RFD_{rel} (N/s$^{-1kgSMM}$)
Superior	7	>118.77	>103.37	>247.54	>239.95	>875.40
Excellent	6	91.28-118.77	82.99-103.37	200.25-247.54	186.55-239.95	685.43-875.40
Good	5	77.54-91.27	72.80-82.98	176.60-200.24	159.90-186.54	590.44-685.42
Average	4	50.04-77.53	52.42-72.79	129.31-176.59	106.44-159.89	400.46-590.43
Satisfying	3	36.30-50.03	42.22-52.41	105.66-129.30	79.74-106.43	305.47-400.45
Not satisfying	2	8.80-36.29	21.83-42.21	58.35-105.65	26.33-79.73	115.48-305.46
Bad	1	<8.80	<21.83	<58.35	<26.32	<115.48

Table 5 shows the defined model of regression equation of the prediction specification of general fitness from the aspect of maximal isometric muscle force (F_{max}) and relative isometric muscle force (F_{rel}_SMM) for male (M) and female (F) athletes.

Table 5 The final model for quantitative estimation of maximal isometric muscle force (F_{max}) and relative isometric muscle force (F_{rel}_SMM) preparedness level for male (M) and female (F) athletes

Bod_SCORE_F_{max} (M)=   -31.5209+0.0415*HGL_F_{max}+0.0384*HGR_F_{max}+0.0139*DL_F_{max}+0.0148*LE_F_{max} +0.0038*PF_F_{max} Bod_SCORE_F_{max} (F)=   -55.9524+0.0636*HGL_$_{Fmax}$+0.0802*HGR_F_{max}+0.0382*DL_F_{max}+0.0403*LE_F_{max} +0.0063*PF_F_{max}
Bod_SCORE_F_{rel}_SMM (M)=   -59.3835+1.9785*HGL_F_{rel}+1.9634*HGR_F_{rel}+0.7187*DL_F_{rel}+0.7246*LE_F_{rel} +0.1354*PF_F_{rel}
Bod_SCORE_F_{rel}_SMM (F)=   -45.3973+1.6114*HGL_F_{rel}+1.7386*HGR_F_{rel}+0.9351*DL_F_{rel}+0.8125*LE_F_{rel} +0.1680*PF_F_{rel}

Table 6 shows the defined model of regression equation of the prediction specification of general fitness from the aspect of maximal explosive isometric muscle force (RFD_{max}) and relative explosive isometric muscle force (RFD_{max}_SMM) for male (M) and female (F) athletes.

Table 6 The final model for quantitative estimation of maximal explosive isometric muscle force (RFD_{max}) and relative explosive isometric muscle force (RFD_{max}_SMM) preparedness level for male (M) and female (F) athletes

Bod_SCORE_RFD_{max} (M)=   -22.3775+0.0032*HGL_RFD_{max}+0.0043*HGR_RFD_{max}x+0.0023*DL_RFD_{max} +0.0054*LE_RFD_{max}+0.0007* PF_RFD_{max}
Bod_SCORE_RFD_{max} (F)=   4.8579+0.0051*HGL_RFD_{max}+0.0066*HGR_RFD_{max}+0.0023*DL_RFD_{max} +0.0024*LE_RFD_{max}+0.0006* PF_RFD_{max}
Bod_SCORE_RFD_{max}_SMM (M)=   -38.0929+0.1230*HGL_RFD_{rel}+0.1844*HGR_RFD_{rel}+0.1168*DL_RFD_{rel} +0.2381*LE_RFD_{rel}+0.0324* PF_RFD_{rel}
Bod_SCORE_RFD_{max}_SMM (F)=   1.1468+0.1368*HGL_RFD_{rel}+0.1844*HGR_RFD_{rel}+0.0666*DL_RFD_{rel} +0.0706*LE_RFD_{rel}+0.0182* PF_RFD_{rel}

<center>DISCUSSION</center>

Based on the results of the descriptive statistical analysis it can be concluded that the obtained results are in the acceptable range of variation given the fact that for the contractile characteristic F_{max}, the coefficients of variation range from 16.72% (HGR_F_{rel}) to 24.74% (PF_F_{max}) for the sub-sample of male athletes, while for the sub-sample of female athletes the coefficients of variation for the same contractile characteristic range from 10.64% (DL_F_{max}) to 26.86% (HGL_F_{max}). When observed in relation to contractile characteristic RFD_{max}, i.e. maximal explosive isometric muscle force, the coefficients of variation of the results range from 22.45% (LE_RFD_{rel}) to 41.97% (DL_RFD_{max}) for the male athlete sub-sample, while in the female athlete sub-sample %cV ranges from 30.92% (DL_RFD_{rel}) to 43.43% (HGL_RFD_{max}). The results of the Shapiro-Wilk test of normality of the distribution have shown a statistically significant deviation of the results in relation to the hypothetical normal curve for the variables PF_F_{rel} (W=0.768, p=0.002) and PF_RFD_{rel} (W=0.847, p=0.020) while for all other variables the distribution of the results was estimated to be approximately normal. On the basis of all aforementioned, it can be argued that the obtained results have average homogeneity (Perić, 2003) and, on a general level, normal distribution, which makes them representative in terms of further scientific interpretation.

When observed in relation to the maximal isometric muscle force of the left hand flexor muscles (HGL_F_{max}), it can be argued that at the level of the sub-sample of male athletes, average absolute values of the measured results were 427.23±97.04 N, that is, 12.00±2.99 N·kg_{SMM}^{-1} relativized in relation to the skeletal muscle mass (SMM). The average result at the level of the female athlete sub-sample for the same muscle group was 240.83±64.70 N in relation to the absolute values of the maximal isometric muscle force, that is 9.22±2.33 N·kg_{SMM}^{-1} relativized in relation to skeletal muscle mass. For the same muscle group, i.e. variable HGL_RFD_{max}, absolute values of maximal explosive muscle force at the level of 2614.85±740.27 N·s^{-1} and 1651.33±717.22 N·s^{-1} were determined for the male and female sub-sample, respectively. Considering relative values of the given contractile characteristic, male athletes achieved an average result of 73.59 N/$s^{-1kgSMM}$, while female cadet athletes achieved an average result of 63.78±27.49 N/$s^{-1kgSMM}$.

In relation to the achieved level of development of the variable HGR_F_{max}, i.e. maximal isometric muscle force of the right hand flexor muscles, on the basis of the obtained results, it can be argued that the tested male judo athletes have achieved an average result of 448.92±100.58 N or 12.57±2.10 N·kg_{SMM}^{-1} for the relative value of the force in relation to skeletal muscle mass (SMM). Considering the results obtained for the female athlete sub-sample, it can be argued that values determined for the same variable were, on average, at the level of 241.83±47.61 N or 9.35±2.21 N·kg_{SMM}^{-1} relativized in relation to skeletal muscle mass. Considering the contractile characteristic RFD_{max}, i.e. maximal explosive isometric muscle force, for the variable HGR_RFD_{max} it can be argued that male athletes have achieved average absolute values of 2658.85±795.60 N·s^{-1} or 74.80±20.86 N/$s^{-1kgSMM}$ relativized in relation to skeletal muscle mass. On the level of the female athlete sub-sample it can be concluded that average values of 1633.00±554.26 N·s^{-1} or 62.60±20.39 N/$s^{-1kgSMM}$ were determined.

Regarding the results achieved on the dead lift test, that is, in terms of the achieved level of development of the variable DL_F_{max}, on the basis of the obtained results it can

be argued that the tested male judo athletes on average achieve maximum isometric muscle force at the level of 1264.62±299.25 N, while female athletes achieved an average value of the given contractile characteristic at the level of 714.50±76.04 N. Relativized in relation to skeletal muscle mass (SMM), male athletes achieve maximal isometric muscle force at the level of 35.42±6.52 $N \cdot kg_{SMM}^{-1}$, while females on average achieved 27.41±3.41 $N \cdot kg_{SMM}^{-1}$. When it comes to the DL_RFD$_{max}$ variable, that is, maximal explosive isometric muscle force of the same muscle group, average values at the level of 6697.69±2810.77 $N \cdot s^{-1}$ and 4038.67±1446.81 $N \cdot s^{-1}$, were determined for the male and female sub-samples, respectively. Relativized in relation to skeletal muscle mass (SMM), the average values of the obtained results are at the level of 186.70±64.24 $N/s^{-1kgSMM}$ and 152.95±47.30 $N/s^{-1kgSMM}$ for male and female athletes respectively.

On the leg extension test, male participants on average achieved absolute values of maximal isometric muscle force (LE_F$_{max}$) on the level of 1151.54±254.22 N, that is 32.25±5.20 $N \cdot kg_{SMM}^{-1}$ relative to the mass of skeletal muscles. At the female sub-sample level, for the same muscle group, an average score at the level of 634.00±99.29 N was determined, that is, it can be said that the maximal isometric muscle force of the given muscle group relative to the mass of skeletal muscles is on average 24.47±4.82 $N \cdot kg_{SMM}^{-1}$. For the variable LE_RFD$_{max}$, that is maximal explosive isometric muscle force of the leg extensor muscles, average values of 4852.23±1238.52 $N \cdot s^{-1}$ and 136.52±30.65 $N/s^{-1kgSMM}$, were determined for the male athlete sub-sample considering absolute and values relative to skeletal muscle mass, respectively. For the female athlete sub-sample, average absolute values of the given contractile characteristic were determined at the level of 3466.00±1489.33 $N \cdot s^{-1}$, while in relation to skeletal muscle mass (SMM) the average value of the results was 133.13±53.41 $N \cdot s^{-1}$.

The obtained results for the variable PF_F$_{max}$ indicate that at the level of the male athlete sub-sample the average absolute value of the results of the contractile characteristic F$_{max}$, that is, maximal isometric muscle force of the ankle joint plantar flexor muscles, is at the level of 3177.54±786.16 N while for the female athlete sub-sample the absolute average value at the level of 2917.17±572.43 N was determined. When observed relative to the skeletal muscle mass (SMM), male cadets achieved an average score at the level of 89.58±20.70 $N \cdot kg_{SMM}^{-1}$ while female athletes achieved an average result of 111.71 ± 20.86 $N \cdot kg_{SMM}^{-1}$. For the variable PF_RFD$_{max}$, that is, maximal explosive isometric muscle force of the ankle joint plantar flexor muscles, average values of 14252.08±3634.52 $N \cdot s^{-1}$ and 402.60±99.41 $N/s^{-1kgSMM}$, were determined for the male athlete sub-sample considering absolute and values relative to skeletal muscle mass, respectively. For the female athlete sub-sample average absolute values of the given contractile characteristic were determined at the level of 13026±5352.60 $N \cdot s^{-1}$, while in relation to skeletal muscle mass (SMM), the average value of the results was 495.44±189.98 $N \cdot s^{-1}$.

On the basis of all the afore mentioned, mathematical models were defined for male and female judo athletes' performance considering each of the relevant dimensions of isometric muscle force, i.e. maximal isometric muscle force (F$_{max}$) and maximal explosive isometric muscle force (RFD$_{max}$), both in absolute terms and considering results relative to skeletal muscle mass. The defined models have shown absolute predictive potential on a given sample, in all cases explaining 100% of the measured variance ($_{Adj}R^2$ = 1,000), with minor prediction error values ranging from 0.0000 for Bod _SCORE_F$_{max}$ (M) up to

0.00542 for Bod_SCORE_F_{rel}_SMM (F). The influence of individual variables on the general point score in each of the defined models, both for maximal isometric muscle force (F_{max}) and maximal explosive isometric muscle force (RFD_{max}), i.e. explosiveness, can be assessed from the values of the Multivariate regression analysis (MRA) coefficients for each of the variables, that is, muscle groups included in the model.

In relation to the previous, a slightly increased influence of the right (HGR) and left (HGL) hand grip variables on a general point score is evident in both male and female maximal isometric muscle force (F_{max}) models. Leg (LE) and back (DL) extensor maximal isometric muscle force relatively equally affects general performance, while plantar flexor muscles (PF) have the least influence (Table 5). For the RFD_{max} models, both absolute and relative to skeletal muscle mass, MRA coefficient values indicate that individual muscle groups, i.e. variables, relatively equally affect general performance considering either male or female athletes (Table 6).

CONCLUSION

The aim of this paper is to define the initial quantitative model and qualitative standard values for evaluation of maximal isometric muscle force (F_{max}) and maximal explosive isometric muscle force (RFD_{max}) in systematically trained and selected cadet judo athletes, both considering absolute values of the obtained results and values derived by relativization of absolute values in relation to skeletal muscle mass (SMM). Given the fact that the coefficient of variation (%cV), as a relative measure of variability of the data, indicates an average or higher level of homogeneity for all tested variables, and the results of the Shapiro-Wilk test of normality of distribution indicate normal distribution for 38 of the 40 variables it is reasonable to conclude that the obtained results are valid for initial diagnostic use. Taking into account that standard values of the examined contractile characteristics in relation to judo sport and cadet age cannot be found in available scientific literature, and the fact that there is no quantitative data in relation to the methodological aspect of the partialization of results in relation to skeletal muscle mass, the results of this research represent the initial standard values of the measured contractile characteristics, and are primarily aimed to be a basis for qualitative assessment of the level of preparedness of athletes from this aspect. Furthermore, the presented multidimensional models of contractile potential estimation and prediction provide a basis for effective monitoring of training progression and implementation of adequate training routines, all in functions of maximization of athletes' development in this initial stage of sport specialization. In general, all of the afore mentioned will contribute to the increase in the knowledge base in the system of preparation of young judo athletes and possibly lead to consequent improvement of existing technology of sports preparation in judo sport.

REFERENCES

Blais, L., Trilles, F., & Lacouture, P. (2007). Validation of a specific machine to the strength training of judokas. *Journal of Strength and Conditioning Research*, *21*(2), 409-412.

Calmet, M., Miarka, B., & Franchini, E. (2010). Modeling of grasps in judo contests. *International Journal of Performance Analysis in Sport*, *10*(3), 229-240.

Cuk, Š., Bratić, M., & Mučibabić, M. (2016). The motor potential of young judokas in Slovenia. Facta Universitatis, series: Physical Education and Sport, 14 (2), 297-305.

Detanico, D., Budal Arins, F., Dal Pupo, J., & Dos Santos, S.G. (2012). Strength parameters in judo athletes: an approach using hand dominance and weight categories. *Human Movement*, *13*(4), 330-336.

Dopsaj, M., Milošević, M., Blagojević, M. (2000). *Analysis of the reliability and factoral validity of selected muscle force mechanical characteristics during isometric multi joint test*. In Y. Hong, & D.P. Johns (Eds.), Proceedings of XVIII International Simposium on Biomechanics in Sport, (146-149). Hong Kong: Department of sports science and physical education – The Chinese University of Hong Kong.

Dopsaj, M., Koropanovski, N., Vučković, G., Blagojević, M., Marinković, B., & Miljuš, D. (2007). Maximal isometric hand grip force in well-trained university students in Serbia: Descriptive, functional and sexual dimorphic model. *Serbian Journal of Sports Sciences*, *1*(4), 138-147.

Dopsaj, M., Ćopić, N., Nešić, G., & Sikimić, M. (2010). A simple mathematical model for estimating general jumping preparedness of senior female volleyball players. *Exercise and Quality of Life*, 2(2), 63-74.

Dopsaj, M. (2015). *Analitika i dijagnostika u sportu i fizičkom vaspitanju (Analytics and diagnostics in sports and physical education)*. Faculty of Sport and Physical Education, University of Belgrade. In Serbian

Dopsaj, M., Ilić, V., Đorđević-Nikić, M., Vučković, M., Eminović, F., Macura, M., & Ilić, D. (2015). Descriptive model and gender dimorphism of body structure of physically active students of Belgrade University: Pilot study. *Anthropologist*, *19*(1), 239-248.

Franchini, E., Nunes, A. V., Moraes, J. M., & Del Vecchio, F. B. (2007). Physical fitness and anthropometrical profile of the Brazilian male judo team. *Journal of Physiological Anthropology*, *26*(2), 59-67.

Franchini, E., Del Vecchio, F.B., Matsushigue, K.A., & Artioli, G.G. (2011). Physiological profiles of elite judo athletes. *Sports Medicine*, *41*(2), 147-166.

Ivanović, J., & Dopsaj, M. (2013). Reliability of force–time curve characteristics during maximal isometric leg press in differently trained high-level athletes. *Measurement*, *46*(7), 2146-2154.

Koprivica, V. (2013). *Teorija sportskog treninga (Theory of sports training)*. Autonomous Edition of Author: Belgrade. In Serbian

Laskowski, R., & Suchanowski, A. (2010). Maximal strength development in a yearly training cycle of judo competitors. *Journal of Combat Sports and Martial Arts*, *1*(2), 41-44.

Marcon, G., Franchini, E., Jardim, J.R., & Barros Neto, T.L. (2010). Structural analysis of action and time in sports: judo. *Journal of Quantitative Analysis in Sports*, *6*(4).

Marković, S., Dopsaj, M., Jovanović, S. (2017). *Multidimensional model of general contractile potential estimation of basic muscle groups in cadet judo athletes*. In S. Pantelić (Ed.). International Congress "FIS Comunications", Book of Procedings (pp. 55-61). Niš: Faculty of Sport and Physical Education, University of Niš.

Milišić, B. (2003). *Upravljanje treningom (Training management)*. SIP: Belgrade. In Serbian

Monteiro, L., Chambel, L., & Cardoso, M. (2011). *Elite and sub-elite judokas: the factors behind international success*. In A.A. Figueiredo & C. Gutierrez-Garcia (Ed.). Scientific congress on martial arts and combat sports, proceedings (pp.73-76). Viseau: Instituto Politecnico de Viseau.

Monteiro, L. (2016). *Analysis of rate force development, power and resistance explosive strength indicators in top elite vs. elite male judokas*. In H. Sertić, S. Čorak & Segedi (Eds.). Applicable Research in Judo Proceedings book, pp. 36-39. Poreč: Faculty of Kinesiology, University of Zagreb.

Nurkić, M., Bratić, M., Mitić, D., Kafentarakis, I. (2017). The differences in the motor area of cadet and junior age judokas. Facta Universitatis, series: Physical Education and Sport, 15 (1), 83-92.

Perić, D. (2003). *Statistika primenjena u sportu i fizičkom vaspitanju (Statistics applied in sports and physical education)*. Belgrade: Faculty of Sport and Physical Education. In Serbian

Pocecco, E., Ruedl, G., Stankovic, N., Sterkowicz, S., Del Vecchio, F.B., Gutiérrez-García, C., & Menz, V. (2013). Injuries in judo: a systematic literature review including suggestions for prevention. *British Journal of Sports Medicine, 47*(18), 1139-1143.

Saraiva, A.R., Reis, V.M., Costa, P.B., Bentes, C.M., Costa e Silva, G.V., & Novaes, J.S. (2014). Chronic effects of different resistance training exercise orders on flexibility in elite judo athletes. *Journal of Human Kinetics*, *40*(1), 129-137.

Sindik, J., Rendulić, D., Čorak, S., & Lewis A.P. (2014). Analysis of the relevant factors of retaining women in judo. *Montenegrin Journal of Sports Science and Medicine, 3*(2), 23-31

Sport and organization rules of the International Judo Federation (Edition 2017). (2017). Laussane, Switzerland: International Judo Federation.

Stamenković, S., Stanković, N., Nurkić, M., Nikolić, D., & Petković, E. (2016). The difference in some motor skills between judokas and non-athletes of an early school age. Facta Universitatis, Series Physical Education and Sport, 14 (2), 201-209.

Thomas, S.G., Cox, M.H., LeGal, Y.M., Verde, T.J., & Smith, H.K. (1989). Physiological profiles of the Canadian National Judo Team. *Canadian Journal of Sport Sciences, 14*(3), 142-147.

Zatsiorsky, V. (1982). *Спортивная метрлогия (Sports metrology). Moscow:* Physical Education and Sports. In Russian

KVALITATIVNA I KVANTITATIVNA PROCENA KARAKTERISTIKA IZOMETRIJSKE MIŠIĆNE SILE RAZLIČITIH MIŠIĆNIH GRUPA KOD DŽUDISTA KADETSKOG UZRASTA: MULTIDIMENZIONALNI MODEL U ODNOSU NA POL

Cilj ovog rada je da se definiše incijalni kvantitativni i kvalitativni model za procenu bazičnih karakteristika izometrijske mišićne sile (jačine) kod sistematski treniranih i selektiranih džudista kadetskog uzrasta. U ovom istraživanju razmatrane su apsolutne vrednosti dobijenih rezultata kao i izvedene vrednosti dobijene relativizacijom rezultata u odnosu na masu skeletnih mišića (SMM). Osnovni metod primenjen u ovom istraživanju je bilo laboratorijsko testiranje. Svi podaci su prikupljeni primenom izometrijske tenziometrije, pomoću tenziometrijskih sondi. Uzorak ispitanika u ovom radu činilo je 21 sportista kadetskog uzrasta, od čega 14 muškaraca i 7 žena. Sva merenja su izvršena primenom standardizovanih procedura testiranja na sledećim mišićnim grupama: mišići pregibači prstiju leve (HGL) i desne (HGR) šake, mišići opružači leđa (DL) i nogu (LE) i mišići plantarni fleksori skočnog zgloba (PF). Na osnovu dobijenih rezultata definisani su odvojeni multidimenzionalni matematički modeli za procenu nivoa pripremljenosti i kontraktilnog potencijala za obe osnovne karakteristike izometrijske mišićne sile: maksimalnu izometrijsku mišićnu silu (F_{max}) i maksimalnu ekplozivnu izometrijsku mišićnu silu (RFD_{max}). Kvalitativna procena kontraktilnog potencijala za svaku od testiranih mišićnih grupa, odnosno varijabli, je omogućena definisanjem normativnih vrednosti za 7 nivoa pripremljenosti za obe osnovne kontraktilne karakteristike mišićne sile, kako za muške, tako i za ženske takmičare kadetskog uzrasta u džudo sportu.

Ključne reči: *džudo, kadeti, izometrijska mišićna sila, normativne vrednosti, model*