UDC:796.012.3:612.766
doi: 10.5937/fizkul75-39013

RELIABILITY AND DIFFERENCES BETWEEN THE CLASSIC AND THE IMPULSE MODEL OF ISOMETRIC TESTING IN FUNCTION OF MAXIMAL AND EXPLOSIVE STRENGTH: PILOT RESEARCH

Milivoj Dopsaj[1], Dragan Klisarić[2], Marko Kapeleti[2], Miloš Ubović[2], Nemanja Rebić[2], David Piper[2], Bogdan Trikoš[2], Damjan Stančić[2], Nemanja Samardžić[2], Aleksandar Rajković[2], David Nikolić[2], Milan Nikolić[2], Marko Vasiljević[1], Branislav Božović[2]

[1]Faculty of Sport and Physical Education, University of Belgrade, Serbia
[2]Faculty of Sport and Physical Education, University of Belgrade, student DAS, Serbia

Abstract

The evaluation of maximal and explosive strength with isometric testing has a significant role in scientific and training practice, from which can be drawn needed information about the segment of the physical state of athletes. The aim of this research was to examine the reliability of the impulse model of isometric testing and to determine the quantitative differences in maximal and explosive strength in accordance to the classic and the impulse model of isometric testing. The laboratory method with tensiometric dynamometry was applied. The research was conducted on a sample of 28 adult and physically active participants. Tests for plantar flexors (PF), right handgrip (HGR), and left handgrip (HGL) were implemented, and all participants had three attempts for each test. Four variables were measured: maximal strength – F_{max}, maximal explosive strength - RFD_{max}, time for maximal strength exertion – tF_{max}, time for maximal explosive strength exertion - $tRFD_{max}$ for both models of testing for each test, implementing a standardized testing procedure. Performed data analysis included descriptive and correlation statistics, and a t-test for determining differences for dependent samples. Statistically significant differences ($p < 0.05$) were found between $F_{max,}$ $RFD_{max,}$ tF_{max} and $tRFD_{max}$ in PF, HGR and HGL, except for $tRFD_{max}$ between classic and impulse models of testing. Impulse model has excellent reliability (ICC = 0.909 – 0.989) for PF, HGR, and HGL tests. The initial results of this study implicate approval for correction of the isometric testing procedure in the next direction: for measuring maximal strength it is approved to use the classic model of isometric testing, while for measuring explosive strength it is approved to use the impulse model.

Key words: DIFFERENCES / TESTING / MEASURING MODELS / CONTRACTILE ABILITIES

Correspondence with the authors: Dragan Klisarić, E – mail: dklisaric94@gmail.com

INTRODUCTION

Muscle strength represents the ability of man to resist external load (Zatsiorsky et al., 2020), and it presents one of the most important physical abilities for people's everyday, athletes and executing professional jobs. Underdeveloped muscle strength can lead to sedentary patterns, and consequently to bad health, a higher risk of injuries and low sports performance (Lehance et al., 2009, Geneen et al., 2017; Kunutsor et al., 2020; De lima et al., 2021, Maestroni et al., 2020). Also, higher levels of upper and lower body muscle strength are related with a lower risk of adult mortality, independently of age factor (García-Hermoso et al., 2018). Muscle strength is related to higher values of explosive strength (RFD) and sports performances, like jumps, sprints and change of direction (Ivanović et al., 2011; Suchomel et al., 2016; Majstorović et al., 2020).

For sports and training practice key role has quantification of maximal strength (F_{max}) and maximal explosive strength (RFD_{max}). In many sports exist a demand for fast performing moves like sprinting, punches in karate, jumps and throwing in track and field, so muscle strength exertion is limited to 50 to 250 ms (Andersen & Aagaard, 2006). It is important to have in mind, that for F_{max} exertion in isometric conditions, the needed time for muscle contraction is 300 to 400 ms, and up to 1 – 2 seconds (Zatsiorsky et al., 2020). Contrary to F_{max}, RFD_{max} determines the gradient of strength development that can be exerted in the early phase of muscle contraction, which is a time interval of 250 to 300 ms (Andersen & Aagaard, 2006; Dopsaj et al., 2022).

To conduct a valid and precise evaluation of different mechanical characteristics of muscle strength athletes isometric testing is regularly used (Majstorović et al., 2020; 2021). Isometric testing has some advantages, such as easier implementation contrary to dynamic testing, also it can be done bilateral or unilateral and demand shorter familiarization (introducing participants to testing procedures), but it has also some limitations in terms of low specific assessment for some dynamic sports performances and it demands specialized equipment (McGuigan, 2020). When testing, measured mechanical characteristics F_{max} and RFD_{max} values can depend on verbal instructions which researchers give participants. Instruction „perform the test as fast as you can" resulted in significantly higher ($F = 40.8$, $p < 0.001$) values of RFD_{max} contrary to the instruction „perform the test as hard and fast you can" for flexor muscles in the elbow joint and extensor muscles in the knee joint (Sahaly et al., 2001).

In previous research, the classic model of isometric testing, as a method of the golden standard is used (Wilson & Murphy, 1996; Andersen & Aagaard, 2006; Ivanović et al., 2011; Marković et al., 2018; Majstorović et al., 2021; Dopsaj et al., 2022), which has proven excellent reliability (ICC = 0.98 and 0.92, namely) for variables F_{max} and RFD_{max} (Suzović & Nedeljković, 2009). But, the impulse model of isometric testing for testing maximal and explosive strength was not examined enough, neither its external and ecological validity is determined (Sahaly et al., 2001; Suzović & Nedeljković, 2009). So, the aim of this research was to examine the reliability of the impulse model of isometric testing and to determine the quantitative differences in maximal and explosive strength in accordance to the classic and the impulse model of isometric testing.

METHODS

Non-experimental research was conducted with the use of laboratory testing. In the function of measuring, tensiometric dynamometry was used. Testing was performed by test-retest method, trial by trial on the next muscle groups: plantar flexors and flexors of fingers for left and right hand. The research was conducted by Helsinki declaration postulates (Christie, 2000) and approval of the Ethical committee of the Faculty of sport and physical education, University of Belgrade (ethical approval number 484-2) project (III 47015).

Participants

In the research participated 28 adult, healthy and physically active participants, from which were 7 female (age = 22.27 ± 6.33 years, body height = 166.70 ± 7.38 cm, body mass = 58.67 ± 7.07 kg, and BMI = 21.07 ± 1.63 kg/m^2) and 21 male (age = 30.51 ± 11.24 years, body height = 184.45 ± 5.99 cm, body mass = 89.04 ± 15.66 kg, and BMI = 26.05 ± 3.70 kg/m^2) sex.

Instruments

For measuring the mechanical characteristics of hand flexors, the standardized procedure was used with standardized equipment (Sports Medical Solutions, All4gym d.o.o., Serbia). In previously published research for handgrip test, a high statistically significant reliability was determined (ICC = 0.938 – 0.977, p = 0.000; ICC = 0.903 – 0.971, p = 0.000., namely) for variables F_{max} and RFD_{max} (Marković et al., 2018). For testing the strength mechanical characteristics of plantar flexors, the standardized procedure was used with standardized equipment, also (Sports Medical Solutions, All4gym d.o.o., Serbia). In previous research was determined high statistically significant (p = 0.000) reliability (ICC = = 0.912 – 0.949 and ICC = 0.785 – 0.822, namely) for RFD_{max} for both sexes, (Majstorović et al., 2021).

Testing procedures

Body composition

Body height was measured by an anthropometer by Martin, while participants were standing upright barefoot on a flat surface, placing the heels of the feet together with toes slightly apart. Verbal instruction was given to straighten as much as possible, with the head in the Frankfort plane position. A multichannel bioelectric impedance (InBody 720) was used.

Handgrip test

The test was performed with participants in a sitting position with an extended arm beside the body (angle in the elbow joint of 180°) with mild abduction (5 - 10 cm) for the left and right hand. Two types of testing were performed, for the first (classic model) a verbal instruction was given: „grip the gauge maximally hard and fast as you can, and hold it for 1 to 2 seconds" (Figure 1), while for the second (impulse model), a different verbal instruction was given: „grip the gauge maximally hard and short as you can" (Figure 2). For both types of testing, three attempts were performed, with a pause for 2 minutes between them. In accordance with the testing model, a randomized procedure was used.

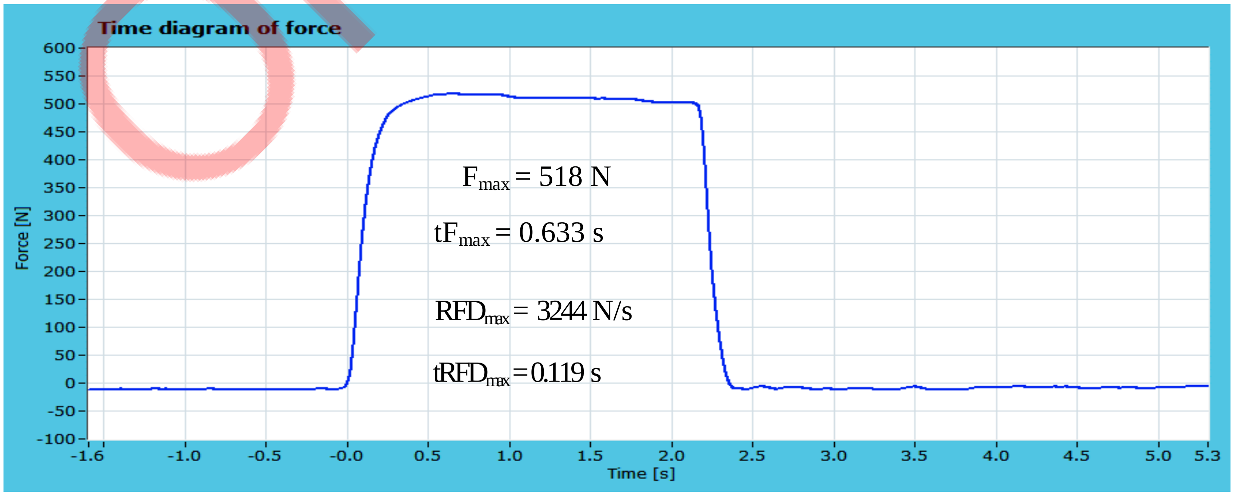

Figure 1 F-t curve record for the classic model of isometric testing for the Handgrip test

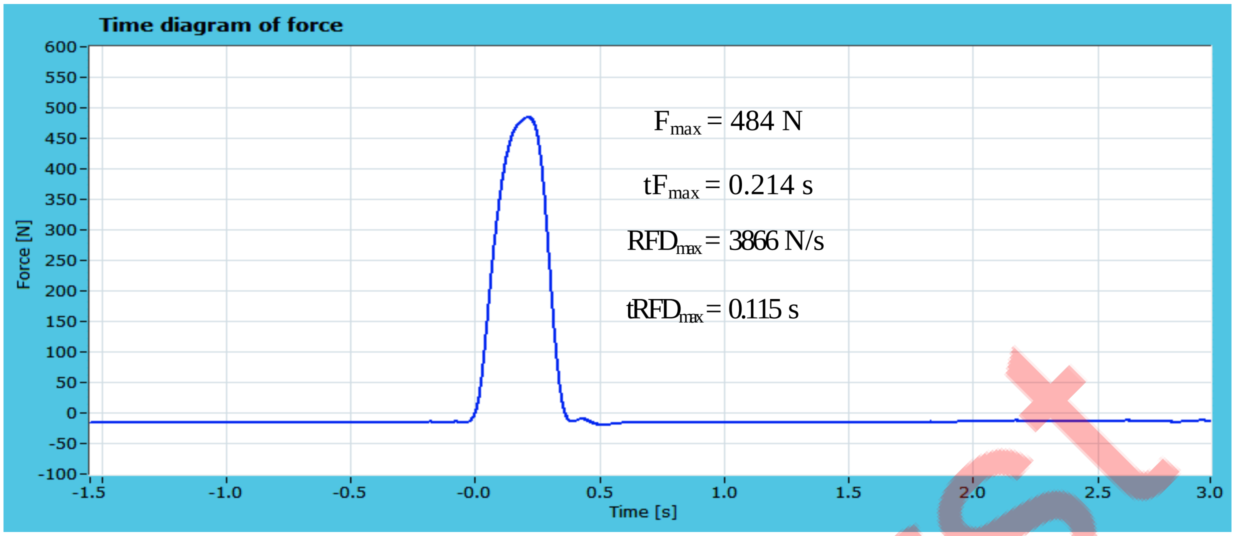

Figure 2 F-t curve record for the classic model of isometric testing for the Handgrip test

Plantar flexors test

The test was performed with participants in a sitting position on a chair with bended knees and feet on the ground. On the upper side of the thighs was placed construction (wooden plate) so that thighs were parallel with the ground, and knees directed in the fingers of feet. Participants were advised to sit with a straight back on 2\3 of the chair. Two types of testing were performed, for the first (classic model) a verbal instruction was given: „push the construction maximally hard and fast you can, and hold it for 1 to 2 seconds", while for impulse testing (impulse model), a different verbal instruction was given: „push the construction maximally hard and short you can". Three attempts were performed for both types of testing, with a pause of 2 minutes between them (Majstorović et al., 2020). A randomized measuring procedure was used according to the testing model.

All tests were conducted at the Faculty of Sport and Physical Education, University of Belgrade, in the Methodological Research Laboratory (MIL) between 14:00 and 17:00 PM.

Variables

In total, four variables were measured for maximal and explosive strength for every test (PF - Plantar flexors, HGR - Right handgrip, and HGL - Left handgrip) and testing model (classic and impulse):

- F_{max} – maximal isometric voluntary strength, expressed in Newtons (N),
- RFD_{max} - maximal isometric voluntary explosive strength, expressed in Newtons per second (N/s),
- tF_{max} – time needed for exerting maximal strength, expressed in seconds (s)
- $tRFD_{max}$ – time needed for exerting maximal explosive strength, expressed in seconds (s)

In test PF the next variables were used: F_{max}_PF_class, RFD_{max}_PF_class, tF_{max}_PF_class, $tRFD_{max}$_PF_class; F_{max}_PF_imp, RFD_{max}_PF_imp, tF_{max}_PF_imp, $tRFD_{max}$_PF_imp. In test HGR the next variables were used: F_{max}_HGR_class, RFD_{max}_HGR_class, tF_{max}_HGR_class, $tRFD_{max}$_HGR_class; F_{max}_HGR_imp, RFD_{max}_HGR_imp, tF_{max}_HGR_imp, $tRFD_{max}$_HGR_imp. In test HGL the next variables were used: F_{max}_ HGL _class, RFD_{max}_HGL_class, tF_{max}_HGL_class, $tRFD_{max}$_HGL_class; F_{max}_HGL_imp, RFD_{max}_HGL_imp, tF_{max}_HGL_imp, $tRFD_{max}$_HGL_imp.

Statistical data processing

Descriptive statistics analysis was performed, with central tendency measures: average value (Mean), Confidence interval 95% (CI 95%), minimum (Min) and maximum (Max) values; measures of spread: standard deviation (SD) and coefficient of variation (cV%). For determining differences between maximal and explosive strength variables, for every test in accordance with the model of testing, a t-test for dependent samples was used. Also, percentual change (Δ) all of the variables (F_{max}, RFD_{max}, tF_{max}, $tRFD_{max}$) for tests PF, HGR and HGL between classic and impulse model was calculated by using the formula:

$$((\text{impulse} - \text{classic}) / \text{impulse}) \cdot 100 \qquad (1)$$

In between test reliability was determined by the intraclass coefficient of correlation (ICC) (relative reliability), in which values less than 0.5 were defined as weak, 0.5 to 0.75 medium, from 0.75 to 0.89 high, and values higher than 0.9 excellent reliability (Koo & Li, 2016). Absolute reliability was determined by the standard error of measurement (SEM), and minimal significant difference (MD) was also calculated. The systematic error of measurement was determined by ANOVA (F and p values). Statistical significance (alpha level) was set at a level of $p < 0.05$. Statistical analysis was performed by IBM SPSS software, version 25.0 (Armonk, NY: IBM Corp.).

RESULTS

Results of descriptive statistics for maximal and explosive strength in classic and impulse models in tests PF, HGR and HGL for all tested variables of the whole sample are shown in Table 1.

Table 1 Descriptive statistics for all variables in accordance with body part tested and testing model

Body part tested	**Testing model**	**Variables**	**Mean**	**95% CI**		**SD**	**cV%**	**Min**	**Max**	**K-S test**
				Lower Bound	**Upper Bound**					
Plantar flexors	**Classic**	F_{max}_PF_class	3929	3532.07	4326.58	1024.49	26.1	1985	6723	0.200
		RFD_{max}_PF_class	17572	15737.66	19406.77	4731.16	26.9	7599	27708	0.164
		tF_{max}_PF_class	1.584	1.355	1.814	0.59	37.3	0.580	2.770	0.200
		$tRFD_{max}$_PF_class	0.133	0.126	0.140	0.02	13.6	0.110	0.170	0.000*
	Impulse	F_{max}_PF_imp	3245	2946.18	3543.25	769.90	23.7	1856	4770	0.200
		RFD_{max}_PF_imp	19520	17359.13	21681.79	5573.89	28.6	2432	29281	0.113
		tF_{max}_PF_imp	0.309	0.275	0.342	0.09	28.3	0.180	0.540	0.095
		$tRFD_{max}$_PF_imp	0.127	0.122	0.132	0.01	9.6	0.100	0.150	0.036*
Right hand	**Classic**	Fmax_HGR_class	507	454.14	559.86	136.31	26.9	258	706	0.200
		RFD_{max}_HGR_class	3356	2978.63	3734.23	974.31	29.0	1617	5119	0.200
		tF_{max}_HGR_class	0.832	0.694	0.970	0.36	42.9	0.330	1.430	0.065
		$tRFD_{max}$_HGR_class	0.117	0.113	0.121	0.01	8.1	0.090	0.140	0.000*
	Impulse	Fmax_HGR_imp	478	426.26	528.74	132.13	27.7	245	697	0.200
		RFD_{max}_HGR_imp	3529	3119.31	3938.12	1055.81	29.9	1734	5347	0.077
		tF_{max}_HGR_imp	0.329	0.305	0.353	0.06	18.9	0.210	0.460	0.200
		$tRFD_{max}$_HGR_imp	0.113	0.109	0.116	0.01	8.6	0.100	0.140	0.004*
Left hand	**Classic**	Fmax_HGL_class	494	438.72	550.07	143.58	29.0	233	776	0.069
		RFD_{max}_HGL_class	3215	2824.11	3606.53	1008.91	31.4	1588	5210	0.200
		tF_{max}_HGL_class	0.845	0.758	0.933	0.23	26.7	0.500	1.400	0.200
		$tRFD_{max}$_HGL_class	0.119	0.112	0.125	0.02	14.5	0.100	0.190	0.001*
	Impulse	Fmax_HGL_imp	464	413.78	514.86	130.35	28.1	239	684	0.150
		RFD_{max}_HGL_imp	3362	2970.49	3752.79	1008.74	30.0	1573	4932	0.013*
		tF_{max}_HGL_imp	0.318	0.295	0.341	0.06	18.7	0.220	0.410	0.109
		$tRFD_{max}$_HGL_imp	0.114	0.111	0.117	0.01	7.0	0.100	0.130	0.000*

CI – confidence interval, SD – standard deviation, cV – coefficient of variation, K-S – Kolmogorov Smirnov test of normality (*$p < 0.05$).

Results of differences in maximal and explosive strength are determined by using a t-test for dependent samples, also, a percentual change (Δ) between variables in accordance with the testing model are shown in Figure 3, 4 and 5. (* indicate statistically significant differences $p < 0.05$ between classic and impulse models of isometric testing).

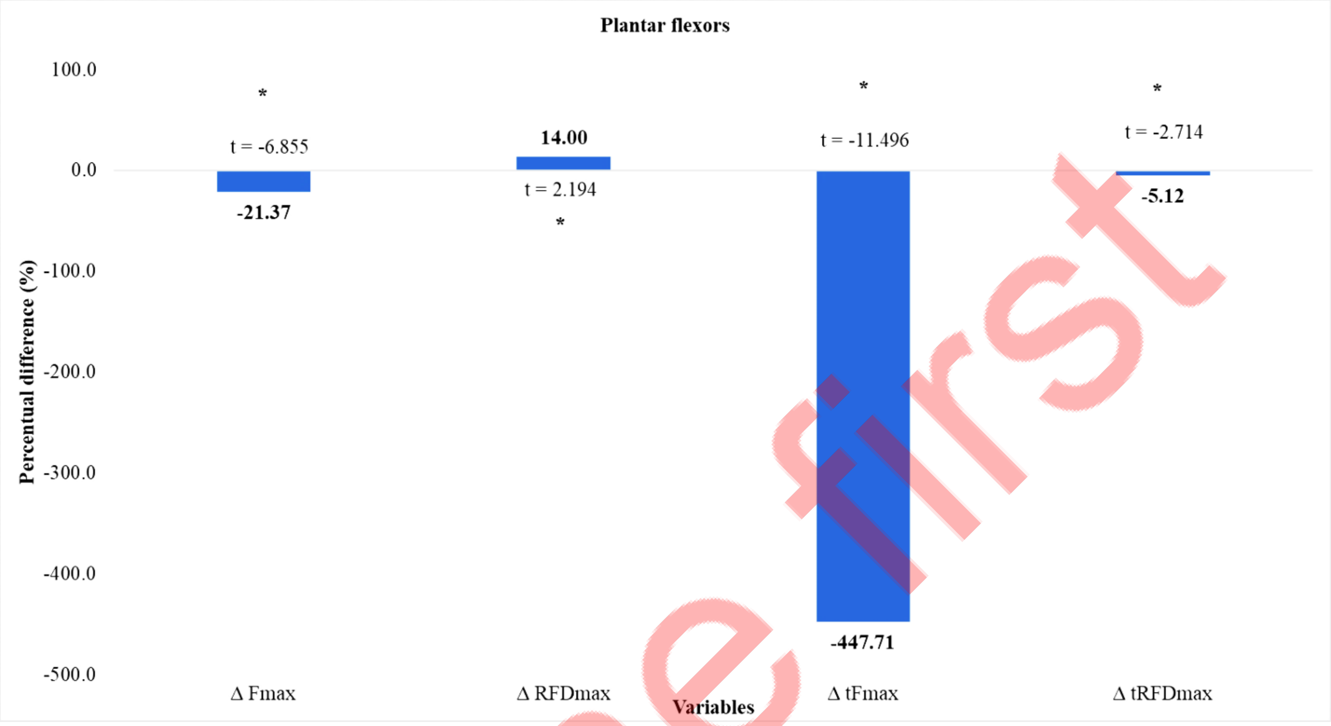

Figure 3 Percentual difference (Δ) of all variables in accordance with the testing model for test PF

In Figure 3 can be seen that significant differences ($p < 0.05$) exist for all variables for test PF. The largest percentual difference (-447.71%) exist for variable ΔtF_{max}, while the smallest percentual difference (5.12%) exists for variable $\Delta tRFD_{max}$.

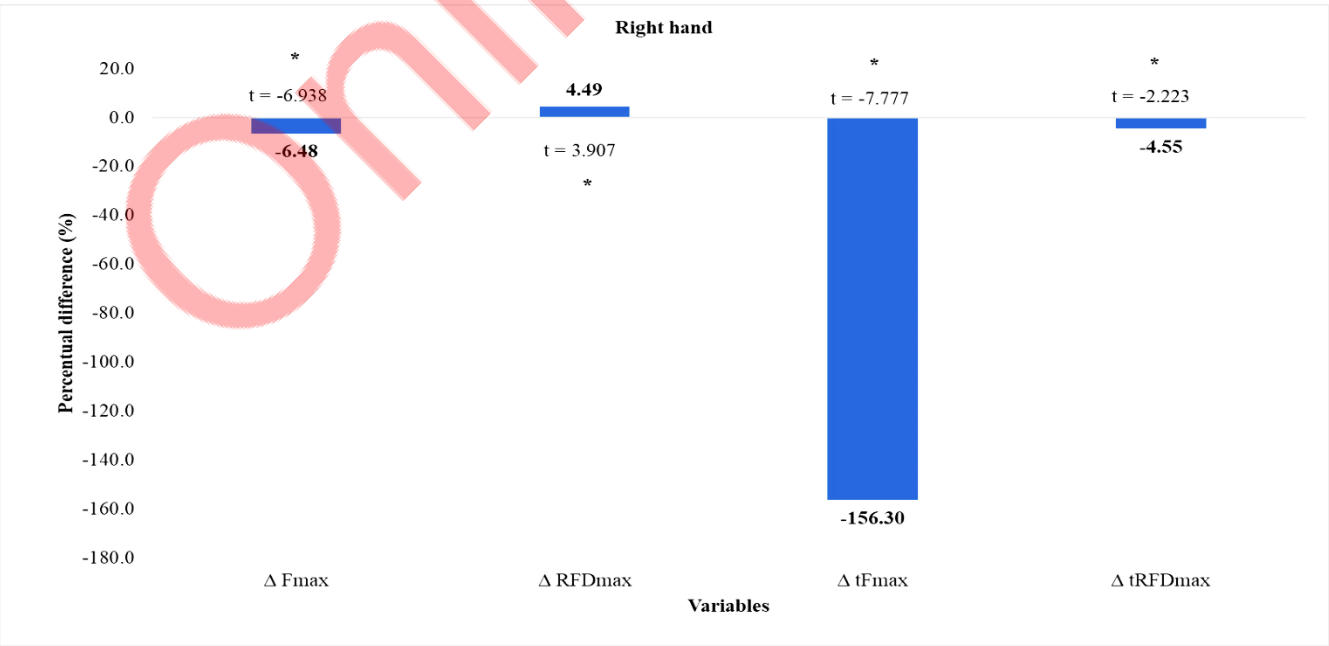

Figure 4 Percentual difference (Δ) of all variables in accordance with the testing model for test HGR

In Figure 4 can be seen that significant differences ($p < 0.05$) exist for all variables for test HGR. The largest percentual difference (-156.30%) exists for variable ΔtF_{max}, while the smallest percentual difference (4.49%) exists for variable ΔRFD_{max}.

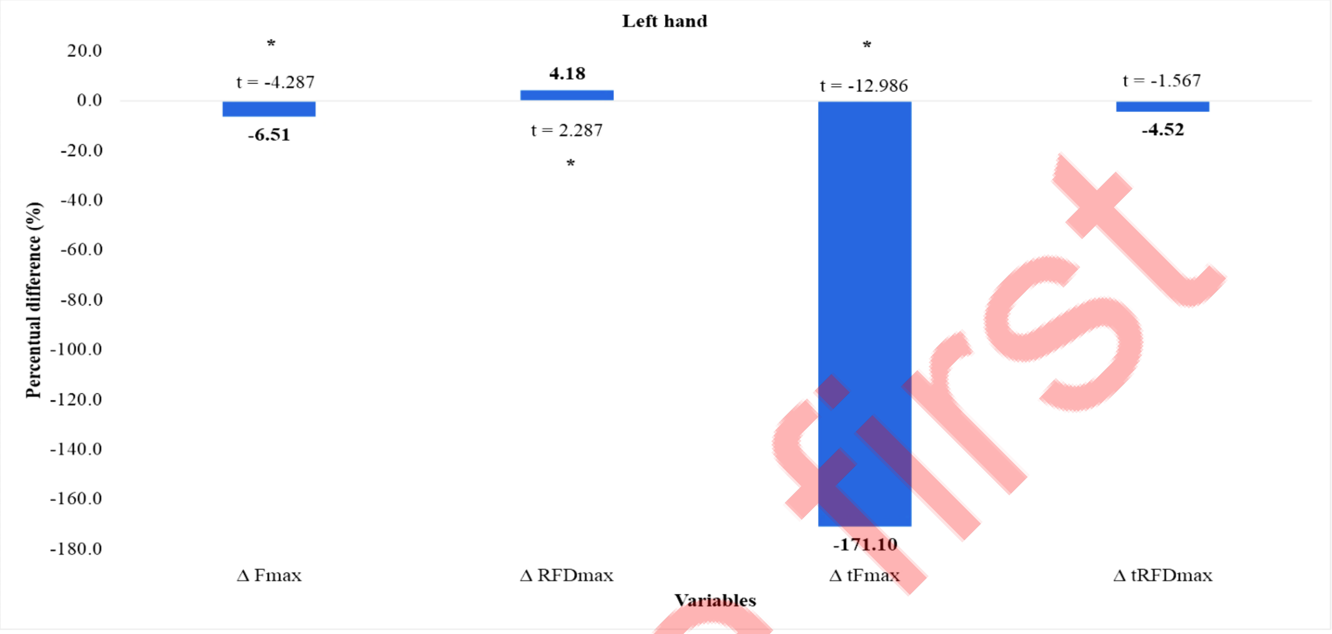

Figure 5 Percentual difference (Δ) of all variables in accordance with the testing model for test HGL

In Figure 5 can be seen that significant differences ($p < 0.05$) exist for all variables for test HGL, except for variable ΔtRFDmax. The largest percentual difference (-171.10%) exists for variable $\Delta tF_{max.}$ The smallest percentual difference (4.18%) exists for variable ΔRFD_{max}.

Results of reliability for impulse model for tests PF, HGR and HGL for maximal and explosive strength variables are shown in Table 2.

Table 2 Results of reliability for tests PF, HGR and HGL for impulse model

Impulse model							
Variables	**ICC (average)**	**CI 95%**		**SEM (N), (N/s)**	**MD (N), (N/s)**	**F test**	**p sig**
		Lower	**Upper**				
F_{max}_PF	.971	0.944	0.986	233.981	648.561	4.030	0.023
RFD_{max}_PF	.909	0.830	0.955	2419.497	6706.505	0.347	0.709
F_{max}_HGR	.986	0.974	0.993	27.189	75.364	0.311	0.734
RFD_{max}_HGR	.984	0.970	0.992	218.219	604.873	0.926	0.402
F_{max}_HGL	.986	0.971	0.993	24.195	67.064	6.874	0.002
RFD_{max}_HGL	.989	0.979	0.995	172.883	479.208	1.061	0.353

Results in Table 2 shows that excellent reliability (ICC = 0.909 – 0.989) exists for maximal strength and explosivity variables in tests PF, HGR and HGL. The largest value of ICC = 0.989 is calculated for variable RFD_{max}_HGL, and the smallest value of ICC = 0.909 is for the variable RFD_{max}_PF.

DISCUSSION

The main aim of this research was to examine the reliability of the impulse model of isometric testing and to determine the quantitative differences in maximal and explosive strength in accordance to the classic and the impulse model of isometric testing. Descriptive statistics show that in all tests (PF, HGR and HGL) larger values of maximal strength (F_{max}) exist in the classic model of isometric contraction than in the impulse model. That implicates that the classic model of isometric testing enables exertion of higher maximal strength than the impulse model. Further, in Figures 3, 4 and 5 the higher values of percentual differences (-21.37%, -6.48% and -6.51%, respectively) in tests PF, HGR and HGL exist for variable ΔF_{max} in the classic model of isometric contraction. Those results are in accordance with the results of research (Christ et al., 1993) where is shown statistically significant difference ($p < 0.05$) in the average value of isometric F_{max} for hand flexors and plantar flexors, when „contract hard" instruction was used in comparison to „contract fast".

Results show that in tests PF, HGR and HGL exist a significant statistical difference ($p < 0.05$) between RFD_{max}_PF_class and RFD_{max}_PF_imp variables. That confirms the hypothesis that difference exists in exerting explosive strength between the impulse and the classic model of isometric testing. Then, contrary to exerted higher values of ΔF_{max} in PF, HGR and HGL in the classic model, for the variable ΔRFD_{max} it can be seen that higher percentual differences (Figures 3, 4 and 5 - 14.00%, 4.49% and 4.18%, respectively) exist for impulse model of isometric testing. It confirms that the impulse model of isometric testing enables higher RFD_{max} values than the classic model. Those results are also in accordance with research (Christ et al., 1993) where statistically significant differences ($p < 0.05$) exist for higher RFD_{max} when „contract fast" than „contract hard" instruction. Also, statistically significant values (30.6%, $p < 0.05$) exist for the variable RFD_{max} when the „contract fast" instruction was used than „contract hard and fast" for isometrically tested extensor muscles in the knee joint, while it's not the case for the F_{max} variable (Jaafar & Lajili, 2018). When muscle strength is tested by using an isokinetic dynamometer (BIODEX System 3 Pro, Biodex Medical Systems, Shirley, NY, USA) statistically significant differences ($p < 0.01$) exist for the variable absolute RFD (RFD_{abs}) calculated from the peak of strength-time (F-t) curve, when „generate strength as fast and hard as you can" instruction was used compared to „generate maximal strength", while F_{max} values were decreased (-0.8%) with second compared to first instruction (Holtermann et al., 2007). Mentioned indicates the importance of instruction specificity which contributes to differences in RFD_{max} in the impulse and the classic models.

Besides, in tests PF, HGR and HGL significant differences ($p < 0.05$) between variables tF_{max}_PF_class and tF_{max}_PF_imp; tF_{max}_HGL_class and tF_{max}_HGL_imp exist. Also, it can be seen that in tests PF, HGR and HGL in the classic model statistically significant longer time is needed for achieving maximal strength than in the impulse model of isometric testing. The largest percentual differences in tests PF, HGR and HGL show variable ΔtF_{max} (-447.71%, -156.30% and -171.10%, respectively) which is in favour of larger values of time parameters in the classic model compared to impulse.

Very similar results in accordance to determined statistically significant differences ($p < 0.05$) are also obtained in $tRFD_{max}$_PF_class and $tRFD_{max}$_PF_imp; RFD_{max}_HGL_class and RFD_{max}_HGL_imp variable values, while statistically significant difference isn't only determined between $tRFD_{max}$_HGL_class and $tRFD_{max}$_HGL_imp variables (Table 1).

Maximal strength variables in the impulse model for all tests show excellent relative measurement reliability, with values of ICC = 0.971 – 0.986, which is also determined for measured variables of explosive strength with values of ICC = 0.909 – 0.989. For the test PF, the impulse model registered higher values of ICC = 0.909 compared to the classic model, where singly values of ICC = 0.822 and ICC = 0.785, respectively for men and women were determined for the RFD_{max} variable (Majstorović et al. 2021). That indicates that variables (for example RFD) which are dependent on time can have excellent reliability when are measured with the impulse model, that is, they don't necessarily must be less reliable than variables which don't depend on time, such as the peak of strength (McGuigan, 2020). Further, the range of ICC = 0.015is smaller for maximal strength variables than ICC = 0.080 for explosive strength variables. Then, maximal strength variables have values of CI 95% = 0.971 – 0.993, while explosive strength variables have values of CI 95% = 0.830 – 0.995 for all tests.

Maximal and explosive strength variables for test HGL show a smaller value of SEM (F_{max}_HGL = 24.2 N and RFD_{max}_HGL = 172.9 N/s) than values of SEM (F_{max}_HGR = 27.2 N and RFD_{max}_HGR = 218.2 N/s) for test HGR. As stated, it can be claimed that test HGR has a lower precision and absolute reliability of maximal and explosive strength than test HGL. A possible reason for that is a lower value agreement of maximal and explosive strength on an individual level (Weir & Vincent, 2012) in test HGR. In order to detect a change in maximal and explosive strength abilities after some training program, a smaller minimal difference (MD = 67.1 N and 479.2 N/s, respectively) for F_{max}_HGL and RFD_{max}_HGL than a minimal difference (MD = 75.4 N and 604.9 N/s, respectively) for F_{max}_HGR and RFD_{max}_HGR. The systematic error of measurement, that is a difference between attempts is significantly different ($p < 0.05$) for variables F_{max}_PF and F_{max}_HGL, which implicates a need for including more testing attempts for measuring mentioned variables.

In this research, based on initial results, it is determined that the impulse model registers higher values of explosive strength and that maximal and explosive strength variables can be measured reliably by the impulse model. Also, results indicate the fact that measuring F_{max} and RFD_{max} demand different, specific instructions. This difference is probably due to the phenomena of faster motor unit discharge (Dideriksen et al., 2020), which represent the key difference in exerting explosive strength compared to maximal strength, consequently originating from the influence of different instructions for maximal isometric exerting (Maffiuletti et al., 2016). Also, because the impulse model demands faster muscle strength exertion than the classic model, a possibility of a more numerous and intense activation of larger motor units that involve faster muscle fibers IIa/IIx type exist (Suchomel, 2018). It has to be noted that it is not known how maximal and explosive strength variables are exerted in different functional and physiological conditions of contraction, such as: according to sex, age, type and training level of participants, different fatigue levels, environmental temperature, different time of a day, different emotional conditions, or under the influence of different pharmacological agents, etc. all in the function of implemented testing models. Thus, to get holistic information about the possibility of the impulse model use, it is needed to conduct further and in-depth research.

CONCLUSION

Higher values of explosive strength are registered in the impulse model, which are exerted for a shorter period of time than in the classic model of isometric testing. On the other side, higher values of maximal strength are registered in the classic model than in the impulse model of isometric testing. Besides, it is proved that among healthy and moderately trained adult persons a statistically significant differences ($p < 0.05$) exist in all variables between the classic and the impulse model of isometric testing in tests PF, HGR and HGL. From the aspect of reliability and measuring maximal explosive strength, for the impulse model is determined excellent reliability of measuring for variables RFD_{max}_PF, RFD_{max}_HGR and RFD_{max}_HGL (ICC = 0.909, 0.984 and 0.989, respectively). Also, in measuring maximal strength, the impulse model shows excellent reliability of measuring for variables F_{max}_PF, F_{max}_HGR and F_{max}_HGL (ICC = 0.971, 0.986 and 0.986, respectively). Based on the initial results of this study, depending on sports needs and goals, for measuring explosive strength it is proposed to use the impulse model, while for measuring maximal strength is proposed to use the classic model. That way enables differentiated, specific and more sensitive measuring of mechanical characteristics of muscles to exert maximal and explosive strength.

REFERENCES

1. Andersen, L. L., & Aagaard, P. (2006). Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. *European Journal of Applied Physiology*, *96*(1), 46-52. doi: 10.1007/s00421-005-0070-z.
2. Christ, C. B., Boileau, R. A., Slaughter, M. H., Stillman, R. J., & Cameron, J. (1993). The effect of test protocol instructions on the measurement of muscle function in adult women. *Journal of Orthopaedic & Sports Physical Therapy*, *18*(3), 502-510.
3. Christie, B. (2000). Doctors revise declaration of Helsinki. BMJ (Clinical Research Ed.), 321(7266), 913. doi:10.1136/bmj.321.7274.1450.
4. De Lima, T. R., Martins, P. C., Guerra, P. H., & Santos Silva, D. A. (2020). Muscular strength and cardiovascular risk factors in adults: A systematic review. *The Physician and Sportsmedicine*, *49*(1), 18-30.
5. Dideriksen, J. L., Del Vecchio, A., & Farina, D. (2020). Neural and muscular determinants of maximal rate of force development. *Journal of Neurophysiology*, *123*(1), 149-157. doi:10.1152/jn.00330.2019.
6. Dopsaj, M., Andraos, Z., Richa, C., Mitri, A., Makdissi, E., Zoghbi, A., ... & Fayyad, F. (2022). Maximal and explosive strength normative data for handgrip test according to gender: international standardization approach. *Human Movement*, *23*(4). https://doi.org/10.5114/hm.2022.108314.
7. García-Hermoso, A., Cavero-Redondo, I., Ramírez-Vélez, R., Ruiz, J. R., Ortega, F. B., Lee, D. C., & Martínez-Vizcaíno, V. (2018). Muscular strength as a predictor of all-cause mortality in an apparently healthy population: a systematic review and meta-analysis of data from approximately 2 million men and women. *Archives of Physical Medicine and Rehabilitation*, *99*(10), 2100-2113. https://doi.org/10.1016/j.apmr.2018.01.008.
8. Geneen, L. J., Moore, R. A., Clarke, C., Martin, D., Colvin, L. A., & Smith, B. H. (2017). Physical activity and exercise for chronic pain in adults: an overview of Cochrane Reviews. *Cochrane Database of Systematic Reviews*, (4). https://doi.org/10.1002/14651858.CD011279.pub3.
9. Holtermann, A., Roeleveld, K., Vereijken, B., & Ettema, G. (2007). The effect of rate of force development on maximal force production: acute and training-related aspects. *European Journal of Applied Physiology*, *99*(6), 605-613. https://doi.org/10.1007/s00421-006-0380-9.
10. Ivanović, J., Dopsaj, M., Ćopić, N., Nešić, G. (2011). Is there a relation between maximal and explosive leg extensors isometric muscle force? *FACTA UNIVERSITATIS Series: Physical Education and Sport, 9(3),* 239 - 254.
11. Jaafar, H., & Lajili, H. (2018). Separate and combined effects of time of day and verbal instruction on knee extensor neuromuscular adjustments. *Applied Physiology, Nutrition, and Metabolism*, *43*(1), 54-62. https://doi.org/10.1139/apnm-2017-0343.
12. Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, *15*(2), 155-163. https://doi.org/10.1016/j.jcm.2016.02.012.
13. Kunutsor, S. K., Seidu, S., Voutilainen, A., Blom, A. W., & Laukkanen, J. A. (2021). Handgrip strength-a risk indicator for future fractures in the general population: findings from a prospective study and meta-analysis of 19 prospective cohort studies. *GeroScience*, *43*(2), 869-880. https://doi.org/10.1007/s11357-020-00251-8.
14. Lehance, C., Binet, J., Bury, T., & Croisier, J. L. (2009). Muscular strength, functional performances and injury risk in professional and junior elite soccer players. *Scandinavian Journal of Medicine & Science in Sports*, *19*(2), 243-251. https://doi.org/10.1111/j.1600-0838.2008.00780.x.
15. Maestroni, L., Read, P., Bishop, C., Papadopoulos, K., Suchomel, T. J., Comfort, P., & Turner, A. (2020). The benefits of strength training on musculoskeletal system health: practical applications for interdisciplinary care. *Sports Medicine*, *50*(8), 1431-1450. https://doi.org/10.1007/s40279-020-01309-5.
16. Maffiuletti, N. A., Aagaard, P., Blazevich, A. J., Folland, J., Tillin, N., & Duchateau, J. (2016). Rate of force development: physiological and methodological considerations. *European Journal of Applied Physiology*, *116*(6), 1091-1116. https://doi: 10.1007/s00421-016-3346-6.

17. Majstorović, N., Dopsaj, M., Grbić, V., Savić, Z., Vićentijević, A., Aničić, Z., ... & Nešić, G. (2020). Isometric strength in volleyball players of different age: A multidimensional model. *Applied Sciences*, *10*(12), 4107. doi:10.3390/app10124107.
18. Majstorović, N., Nešić, G., Grbić, V., Savić, Z., Živković, M., Aničić, Z., ... & Dopsaj, M. (2021). Reliability of a simple novel field test for the measurement of plantar flexor muscle strength. *Revista Brasileira de Medicina do Esporte*, *27*, 98-102. http://dx.doi.org/10.1590/1517-8692202127012019_0002.
19. Marković, M. R., Dopsaj, M., Koropanovski, N., Ćopić, N., & Stanković, M. (2018). Reliability of measuring various contractile functions of finger flexors of men of various ages. *Physical Culture*, *72*(1), 37-48. doi: 10.5937/_zkul1801037M.
20. McGuigan, M. (2020). *Testing and Evaluation of Strength and Power*. New York: Routledge Taylor & Francis Group.
21. Sahaly, R., Vandewalle, H., Driss, T., & Monod, H. (2001). Maximal voluntary force and rate of force development in humans–importance of instruction. *European Journal of Applied Physiology*, *85*(3), 345-350.
22. Suchomel, T. J., Nimphius, S., & Stone, M. H. (2016). The importance of muscular strength in athletic performance. *Sports Medicine*, *46*(10), 1419-1449. doi: 10.1007/s40279-016-0486-0.
23. Suchomel, T. J., Nimphius, S., Bellon, C. R., & Stone, M. H. (2018). The importance of muscular strength: training considerations. *Sports Medicine*, *48*(4), 765-785. https://doi.org/10.1007/s40279-018-0862-z.
24. Suzović D, Nedeljković A. (2009). Kratke pulsne kontrakcije: odnos između maksimalne sile i brzine razvoja sile. [Short pulse contractions: relationship between maximal forces and rate of force development]. *Physical Culture*, 63(1), 17-34.
25. Weir, J. P., & Vincent, W. J. (2012). *Statistics in Kinesiology*. Champaign, IL: Human Kinetics.
26. Wilson, G. J., & Murphy, A. J. (1996). The use of isometric tests of muscular function in athletic assessment. *Sports Medicine*, 22(1), 19-37.
27. Zatsiorsky, V. M., Kraemer, W. J., & Fry, A. C. (2020). *Science and Practice of Strength Training*. Champaign, IL: Human Kinetics.