THE RELIABILITY OF NEWLY DESIGNED SPECIFIC TESTS FOR ASSESSING PROFESSIONAL FIREFIGHTERS' PHYSICAL FITNESS

Original Scientific Article

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Abstract: The aim of this study was to determine the reliability of newly designed tests for assessing professional firefighters' physical fitness. A total of 15 healthy and physically active firefighters participated in this study. The following tests were performed: Modified Step Test ($MS_{tep}T$), Fire and Rescue Obstacle Course (VPol), Firefighting Equipment Carry Test (NVO_{pr}, and Dummy Drag Test (VL_{ut}). The testing was carried out using a randomized method. There was a 10-minute break between the tests. After a week, retesting was conducted under the same conditions. The results of the regression analysis showed that the value of the adjusted coefficient of determination ($adjR^2$) for all tests ranged from 0.90 (90.00%) to 0.98 (98.00%), from $MS_{tep}T$ to NVO_{pr} respectively, and the repeatability (reliability) of the tests in relation to the sample used in testing for all variables was highly statistically significant ($p = 0.000$). A moderate effect size ($d = 0.748$, 95% CI = 0.162 – 1.314) was found for the VPol variable, while the effect size was found small ($d = 0.212 – 0.281$) for the variables ($MS_{tep}T$, NVO_{pr}, VL_{ut}). The findings demonstrated that the examined tests can be applied in the practice of professional firefighters for the purposes of testing physical fitness related to the job. Methodologically, it is acceptable to conduct tests for firefighters in complete PPE so that the test conditions and workload are similar to the situational conditions during intervention in the field.

Keywords: firefighters, specific testing, work capacity, reliability.

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INTRODUCTION

Firefighters are organized differently in different countries, but they are characterized by a common professional duty to protect people and their property from the uncontrolled effects of fire. Firefighters are often organized according to the principle of political neutrality for the common good, but in history this was not always the case. Firefighters are divided into professional firefighters and volunteers. Professional fire brigades can be territorial and industrial, while voluntary ones are founded by citizens who join together in volunteer firefighters associations (VFA). All professional territorial fire brigades in the Republic of Serbia are fire and rescue services within the Ministry of the Interior of the Republic of Serbia, the Sector for Emergency Situations (SES).

Firefighting is recognized as an occupation associated with a high level of physical and psychological demands (Ärnlöv et al., 2011; Baur et al., 2012a; Baur et al., 2012b). Firefighters are faced with diverse and complex situations, which are often dangerous and difficult to deal with (Melius, 2001). For example, fires vary greatly in burning material, size, and weather conditions. The nature and concentration of airborne particles change at a fire location and during stages of a fire (Golden et al., 1995). Firefighters are often exposed to toxic environments and smoke inhalation (Gledhill & Jamnik, 1992; Bergman et al., 2011; Blacker et al., 2016), therefore they must wear personal protective equipment and self-contained breathing apparatus in an attempt to limit exposure. While necessary, this protective equipment can equate to an additional load of more than 20 kg (Guidotti & Clough, 1992), which increases the stress and difficulty (e.g., increased aerobic and anaerobic energy cost, decreased mobility, increased perception of effort) of fireground job tasks (Kales et al., 2007; Jacobsson et al., 2015).

Firefighters are exposed to high rates of traumatic events, such as being assaulted in the line of duty and death/severe injury of victims or fellow firefighters (Hanson et al., 2010; Komarovskaya et al., 2011; Kesler et al., 2021). Firefighters are required to perform numerous demanding and motor-specific tasks when on the fireground, including operating hose lines, carrying equipment, forcible entries, ladder raises, crawling and searching, and victims or casualties drags (Lindberg et al., 2014a; Lindberg, 2014b). Consequently, physical fitness can be an important contributor to firefighter's job performance.

Numerous studies (Shalev et al., 1998; Rhea et al., 2004; Michaelides et al., 2011) recommend that the maximum aerobic capacity (VO2max) be at least 45 ml/kg/min for future firefighter candidates (Gledhill & Jamnik, 1992). Similarly, a study by Michaelides et al. (2011) found a positive relationship between a high level of difficult working conditions and firefighter's job tasks performance. Among several fitness factors, cardiovascular endurance and muscle strength were reported as most important and contribute to more efficient tasks execution in firefighting (Soteriades et al., 2011).

Sothmann et al. (1990) determined that firefighters require a minimum of 45 ml/kg/min of maximum oxygen consumption to safely perform firefighting tasks. This finding is in line with the findings of other similar studies (Williams-Bell et al., 2009; Skinner et al., 2020), which determined that the body needs to absorb at least 40 ml/kg/min of oxygen at an exercise intensity corresponding to 84- 100% of peak heart rate.

Different systems, that is, different countries use different methodologies to assess firefighters' job preparedness and physical fitness. In most modern countries, tests used to assess working physical abilities dominate. For the development of the given area, it is necessary to apply the most adequate, that is, the most expedient testing program for firefighters as a very specific profession.

To ensure general health and adequate physical fitness of firefighters, it is recommended that they wear full PPE during exercise in their firefighting brigades by performing daily activities according to the plan and program related to that working day. Regarding testing, it is best to conduct it twice a year in order to monitor the level of firefighters' physical fitness, wearing full PPE with firefighting equipment while performing tasks.

Until recently, in the system of the Ministry of the Interior of the Republic of Serbia (MUP), the testing of firefighters has been based on a battery of tests assessing only the level of general physical fitness (Pravilnik o kriterijumima za izbor kandidata za polaznike kursa za Osnovnu obuku pripadnika vatrogasno-spasilačke jedinice, *Službeni glasnik RS*, br. 12/2019; 14/2020; 49/2021; 27/2022). Given that firefighters have a very specific job, which implies completely different knowledge, skills and movement activities compared to the rest of the MUP, there is a methodological and professional need to design a new set of tests for assessing physical work abilities. The new set of tests is based on professional tasks and includes the following tests: Modified Step Test, Fire and rescue Obstacle Course, Firefighting Equipment Carry Test, and Dummy Drag Test.

This study aims to determine the reliability of newly designed tests used to assess physical work abilities. High reliability is assumed in the newly designed tests: Modified Step Test ($MS_{tep}T$), Fire and Rescue Obstacle Course (VPol), Firefighting Equipment Carry Test (NVO_{pr}), and Dummy Drag Test (VL_{ut}).

METHODOLOGY

A non-experimental study was carried out using field trials, by means of the test-retest method, using the following modified tests: Modified Step Test ($MS_{tep}T$), Fire Range (VPol), Firefighting Equipment Carry Test (NVO_{pr}) and Dummy Drag Test (VL_{ut}). The study was carried out in accordance with the postulates of the Declaration of Helsinki (Christie, 2000) and with the approval of the Ethics Committee of the Faculty of Sport and Physical Education, University of Belgrade (Ethics Committee permit number 484-2).

Respondents

Fifteen adult, healthy and physically active male respondents, professional firefighters (age = 30.60 ± 5.78, body height = 181.88 ± 6.03 cm, body mass = 86.95 ± 7.64 kg, body mass index - BMI = 26.30 ± 2.18 kg/m^2, and work experience = 5.6 ± 4.3 years) participated in the study.

Instruments

The following tests were used to measure physical fitness of professional firefighter: Modified Step Test ($MS_{tep}T$), Fire and Rescue Obstacle Course (VPol), Firefighting Equipment Carry (NVO_{pr}), and Dummy Pulling test (VL_{ut}).

Measurement procedure

Modified Step Test

Test for assessing cardiovascular capacity in firefighters. Required equipment: a stopwatch, a mobile application called Metronome Pro, and a bench (40cm high). The 60-second test was performed while wearing PPE and a tank. Respondents listened to the sound on their mobile phone's built-in speaker and stepped right, left, right, left to the 4/4 beat/60 BPM. Heart rate was measured 15 seconds after the test. Thereafter, the pulse value after the test and age were entered into the table to calculate the VO2max in the step test (TrainerMetrics app).

Fire and Rescue Obstacle Course

This test/obstacle course is used to test dexterity, agility, coordination and the strength of the whole body, which is 85m long. Firefighters crawled on their knees for 10 m as far as a 12 kg tractor tire; they picked up a 5 kg hammer and punched for 10 reps, ran to an 8 kg truck tire, flipped it back and forth for 6 reps, and continued to run to the grappling hook on top of which there was a 5 kg weight plate, moved it up and down using their arms for 10 reps; then they put down the grappling hook and overcame a 200 cm high fence as the last obstacle. Respondents performed the test wearing full PPE without a tank.

Firefighting Equipment Carry Test

Respondents wore full PPE with a tank and were asked to walk a distance of 22m from one cone (a start point) to another cone (an end point), carrying firefighting equipment:

1) They picked up two 52 mm filled hoses and ran with them for one length of 22 m to the cone, placed them down, then returned to the start point.
2) They picked up two 75 mm coiled hoses by the handles and carried them to the cone, placed them down, then returned to the start point.

3) They picked up one suction hose and a submersible pump, carried them to the cone, placed them down, then they returned to the start point.
4) They picked up two "S9" devices and carried them to the cone; they placed them down and returned to the start.
5) They picked up two buckets (20 kg) of Eco pour and carried them to the cone.

The stopwatch was stopped when respondents reached the second cone.

Dummy Drag Test

Respondents had to wrap their hands underneath the arms of a 75-kilogram dummy and drag it backwards for a length of 15 m, go around the obstacle and drag it back for another length of 15 m to the start. Respondents dragged the dummy over a 30 m distance.

Testing was carried out on the sport court of the Belgrade Fire Brigade in full PPE in the morning hours from 10:00 a.m. to 2:00 p.m. After a detailed explanation of the test tasks and the individual implementation of each test individually with low intensity, and in order to familiarize respondents with the task, respondents did a 10-minute warm-up and had a 10-minute passive rest. Testing sessions were carried out using a randomized testing method. There was a 10-minute break between the tests. After a week, retesting was carried out under the same conditions.

Variables

The following variables were measured in the tests (test and retest):

- $MS_{tep}T$_test – maximum oxygen consumption (ml/kg/min),
- Vpol_test – fire and rescue obstacle course completion time (s),
- NVO_{pr}_test – firefighting equipment carry task completion time (s),
- VL_{ut}_test – dummy drag task completion time (s).

Statistical data processing

A descriptive statistical analysis was performed to calculate measures of central tendency: mean value (Mean), minimum (Min) and maximum (Max) values; measures of dispersion – standard deviation (SD), the coefficient of variation (CV%). The dependent sample t-test was used to analyze differences. Also, the effect size was calculated according to the following formula (Sullivan & Feinn, 2012):

$$d = (Mean1 - Mean2) / SDD \quad (1)$$

where Mean1 – mean value of the test variable; Mean2 – mean value of the retest variable; SDD – difference SD test and retest variable. Effect sizes were

classified as follows: < 0.2 (trivial), 0.2 – 0.49 (small), 0.5 – 0.79 (moderate), and > 0.8 (large) (Cohen, 1988). To assess the degree of agreement of the results of retesting, that is, reliability, a linear regression analysis was performed. Statistical significance (alpha level) was set at $p < 0.05$. Statistical analysis was performed using IBM SPSS software, version 20.0 (Armonk, NY: IBM Corp.)

FINDINGS AND DISCUSSION

The results of descriptive statistical analysis for the test and retest of the completed tests are shown in *Table 1*.

Table 1. Descriptive indicators of all variables

Descriptive statistics						
Variables	N	Mean	SD	CV%	Min	Max
$MS_{tep}T$_test	15.00	50.35	3.05	6.10	45.80	56.70
$MS_{tep}T$_retest	15.00	50.60	3.05	6.00	46.70	56.70
Vpol_test	15.00	69.82	9.76	14.00	57.74	88.00
Vpol_retest	15.00	68.21	9.07	13.30	56.00	84.56
NVO_{pr}_test	15.00	85.18	11.62	13.60	69.46	111.42
NVO_{pr}_retest	15.00	84.69	11.55	13.60	67.26	109.00
VL_{ut}_test	15.00	25.37	5.80	22.90	19.83	41.46
VL_{ut}_retest	15.00	25.08	5.35	21.30	18.69	38.33
Valid N (listwise)	15.00					

N – number, Mean – mean value, SD – standard deviation, CV% - the coefficient of variation, Min – minimal value, Max – maximum value.

Table 1 demonstrates that the mean value for the Modified Step Test variable is 50.35 ± 03.05 ml/kg/min, while in the retest the mean value is 50.60 ± 3.05 ml/kg/min. For the Fire and Rescue Obstacle Course variable the mean value is 69.82 ± 9.76 s, while in the retest the mean value is 68.21 ± 9.07 s. For the Firefighting Equipment Carry variable the mean value is 85.18 ± 11.62 s, while in the retest the average value is 84.69 ± 11.55 s. For the Dummy Drag variable the mean value is 25.37 ± 5.80 s, while in the retest it is 25.08 ± 5.35 s. The coefficient of variation (CV%) does not exceed 30%, which indicates that respondents represent a homogeneous sample in relation to all abilities tested.

Regression analysis results for the Modified Step Test ($MS_{tep}T$) are shown in *Table 2*.

Table 2. Regression analysis for the $MS_{tep}T$ variable

Regression Statistics		ANOVA	
Multiple R	0.95	F	Significance F
R Square	0.91		
Adjusted R Square	**0.90**	**131.05**	**0.000**
Standard Error	**0.95**		
Observations	15		

Table 2 indicates that the adjusted coefficient of determination (Adj.R^2 = 0.90) with the standard error of prediction (SEE = 0.95) is significant (F = 131.05, p = 0.000).

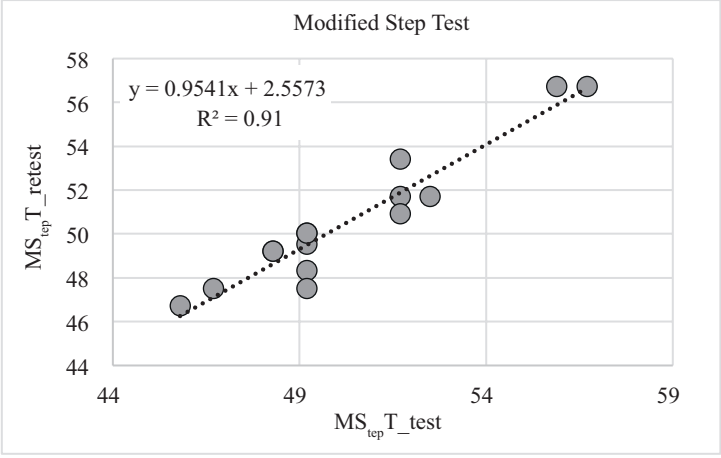

Figure 1. Linear regression of the $MS_{tep}T$_retest variable based on the variable of $MS_{tep}T$_test

Figure 1 shows the linear dependence of the $MS_{tep}T$_retest variable based on the $MS_{tep}T$_test variable, where the coefficient of determination is significant (R^2 = 0.91, p = 0.00), which is greater than the value of 0.90, meaning there is a high degree of reproducibility of the results. All this indicates a reliable application of the Modified Step Test ($MS_{tep}T$)) in practice.

The predictive equation is of the following form: $MS_{tep}T\_retest = 0.9541 \cdot MS_{tep}T\_test + 2.5573$.

Regression analysis results for the Fire and Rescue Obstacle Course (Vpol) are shown in *Table 3*.

Table 3. Regression analysis for the Vpol variable

Regression Statistics		ANOVA	
Multiple R	0.98	F	Significance F
R Square	0.95		
Adjusted R Square	**0.95**	**265.20**	**0.000**
Standard Error	**2.19**		
Observations	15		

Table 3 indicates that the adjusted coefficient of determination is (Adj.R^2 = 0.95) with the standard error of prediction (SEE = 2.19) is significant (F = 265.20, p = 0.000).

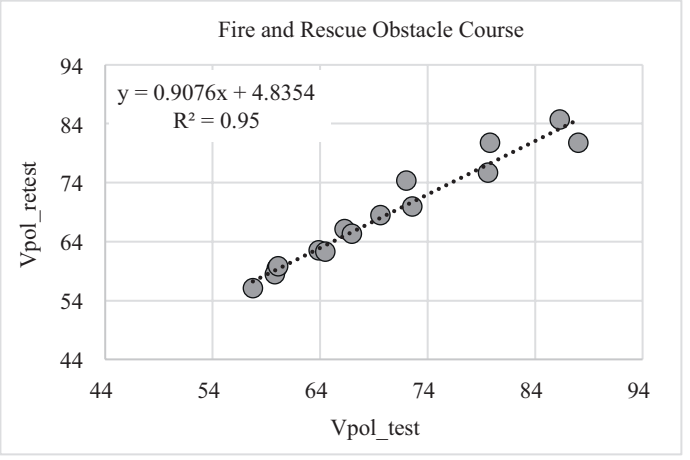

Figure 2. Linear regression analysis of the Vpol_retest variable based on the Vpol_test variable

Figure 2 shows the linear dependence of the Vpol_retest variable based on the variable of Vpol_test, where the coefficient of determination is significant (R^2 = 0.95, p = 0.00), which is greater than the value of 0.90, meaning there is a high degree of repeatability of the results. All this indicates a reliable application of the Fire and Rescue Obstacle Course (Vpol) in practice.

The predictive equation is of the following form: Vpol_retest = 0.9076 · Vpol_test + 4.8354.

Regression analysis results for Firefighting Equipment Carry за (NVO_{pr}) are shown in *Table 4*.

Table 4. Regression analysis for the NVO_{pr} variable

Regression Statistics		ANOVA	
Multiple R	0.99	F	Significance F
R Square	0.98		
Adjusted R Square	**0.98**	**572.86**	**0.000**
Standard Error	**1.80**		
Observations	**15**		

Table 4 indicates that the adjusted coefficient of determination (Adj.R^2 = 0.98) with the standard error of prediction (SEE = 1.80) is significant (F = 572.86, p = 0.000).

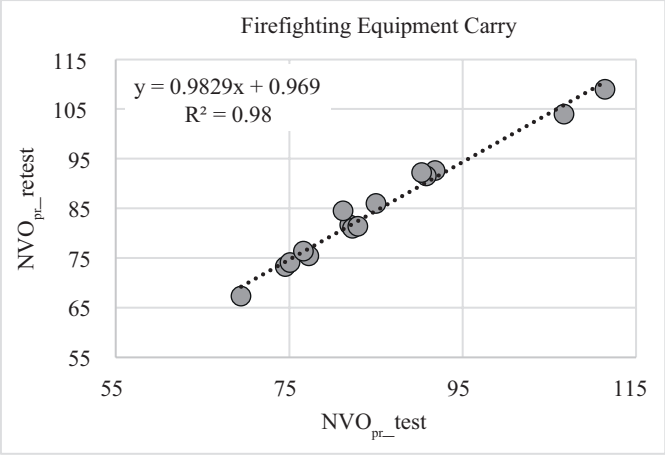

Figure 3. Linear regression of the NVO_{pr}_retest variable based on the NVO_{pr}_test variable

Figure 3 shows that the linear dependence of the NVO_{pr}_retest variable based on the NVO_{pr}_test variable, where the coefficient of determination is significant (R^2 = 0.98, p = 0.00), which is greater than the value of 0.90, meaning there is a high degree of repeatability of the results. All this indicates a reliable application of the Fire and Rescue Obstacle Course (NVO_{pr}) in practice.

The predictive equation is of the following form: NVO_{pr}_retest = 0.9829 · NVO_{pr}_test + 0.969.

Regression analysis results for Dummy Drag (VL_{ut}) are shown in *Table 5*.

Table 5. Regression analysis for the VL_{ut} variable

Regression Statistics		ANOVA	
Multiple R	0.97	F	Significance F
R Square	0.95		
Adjusted R Square	**0.94**	**239.01**	**0.000**
Standard Error	**1.37**		
Observations	15		

Table 5 demonstrates that the adjusted coefficient of determination (Adj. $R^2 = 0.94$) with the standard error of prediction (SEE = 1.37) is significant ($F = 239.01$, $p = 0.000$).

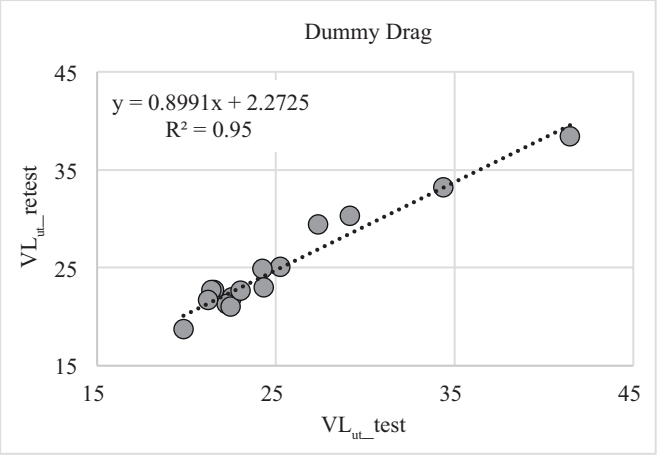

Figure 4. Linear regression of the VL_{ut}_retest variable based on the VL_{ut}_test variable

Figure 4 shows the linear dependence of the VL_{ut}_retest variable based on the VL_{ut}_test variable, where the coefficient of determination is significant ($R^2 = 0.95$, $p = 0.000$), which is greater than the value of 0.90, meaning there is a high degree of reproducibility of the results. All this indicates a reliable application of the Fire and Rescue Obstacle Course (VL_{ut}) in practice.

The predictive equation is of the following form: VL_{ut}_retest = 0.8991 · VL_{ut}_test + 2.2725.

Table 6 shows the results of the dependent sample t-test for all variables.

Table 6. The results of the dependent sample t-test for all variables

Paired Samples Test	Paired Samples Test									
	Paired Differences					t	Sig. (2-tailed)	Cohen d	95% Confidence Interval	
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference					Lower	Upper
				Lower	Upper					
$MS_{tep_}$T_test MS_{tep}T_retest	-0.25	0.93	0.24	-0.76	0.27	-1.03	0.320	-0.27	-0.77	0.25
Vpol_test Vpol_retest	1.62	2.16	0.56	0.42	2.81	2.90	0.012	0.75	0.16	1.31
NVO_{pr}_test NVO_{pr}_retest	0.49	1.73	0.45	-0.47	1.45	1.09	0.296	0.28	-0.24	0.79
VL_{ut}_test VL_{ut}_retest	0.29	1.35	0.35	-0.46	1.03	0.82	0.425	0.21	-0.30	0.72

Table 6 indicates statistically significant (t = 2.90, p = 0.012) differences between the variables Vpol_test and Vpol_retest. No significant differences were found between other variables (p > 0.05). A moderate effect size (d = 0.748, 95% CI = 0.162 – 1.314) was found for the Vpol variable. A small effect size was found for the MS_{tep}T variable (d = -0.27, 95% Cl = -0.77 – 0.25), the NVO_{pr} variable (d = 0.28, 95% Cl = -0.24 – 0.79), and a small effect size was determined for the VL_{ut} variable (d = 0.21, 95% Cl = -0.30 – 0.72).

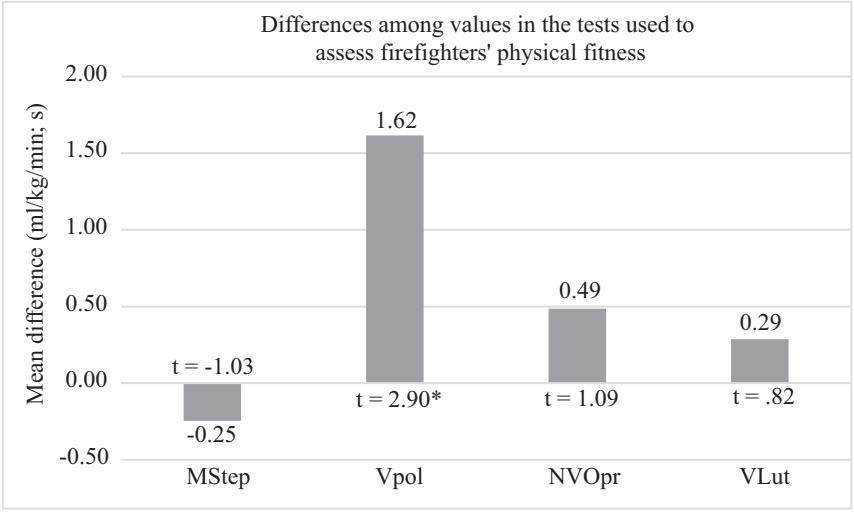

Figure 5. The results of the differences in the mean values of the variables examined on repeat testing (retest) in relation to initial testing (test)

Based on the results of differences in the mean values of the examined tests used for testing (test - retest), it can be claimed that respondents achieved statistically different results only on the Fire and Rescue Obstacle Course (Vpol) test, while they achieved better results on the retest (*Table 1* and *Table 6*). As the test was of a very complex motoric character with very complex motor tasks requiring endurance, it is possible that the better result achieved on the retest is a consequence of a component of motor learning, but also a consequence of respondents' greater self-confidence in terms of the intensity of the performance of the test (they were less "afraid" to perform the test at very high intensity compared to the initial test). Methodologically, for the test to be applied, it is necessary for respondents to perform the test at least once before the actual testing, in order to gain individual experience of its implementation and complete familiarization with the test task, while the actual testing should be performed after a 48 hour-break.

CONCLUSION

Regression analysis results show that there is a high and significant coefficient of determination (adjR2 = 0.90 - 0.98, $p < 0.05$) for all conducted tests (MStepT, Vpol, NVOpr and VLut)). This indicates a high degree of reliability of the conducted tests. No significant ($p > 0.05$) differences were found between test trials on the MStepT, NVOpr and VLut tests. A moderate effect size (d = 0.748, 95% CI = 0.162 – 1.314) was found for the Fire and Rescue Obstacle Course variable. The effect size of other variables was small (d = 0.212 – 0.281). It would prove useful for future research to include a larger number of respondents (including women) and another retest (third attempt).

Based on the obtained results, the examined tests can be applied in the practice of professional firefighters for the purposes of testing physical fitness related to the job. Regular conduct of tests envisaged in monthly work plans and programs should contribute to a more efficient work of firefighters, including annual physical ability testing. In addition, initial testing is recommended when recruiting new firefighters. Also, it can be indirectly concluded that it is methodologically acceptable for firefighters to perform tests wearing full personal protective equipment so that testing conditions and workload are similar to those encountered on the fireground.

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