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THE ANALYSIS OF MAXIMUM FORCES OF FIVE UPPER LIMB ACTIVITIES

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Abstract. The aim of the study was to analyse relationship between strength developed in various types of upper limb activities and body measures (body height and body mass) as well as to compare values of the measured maximal force among the analysed types of strength activities (handgrip, lifting, pushing, pronation and supination). Twelve right hand dominant men in age from 26 to 31 years old participated in the experimental study. All the participants were healthy and had no history of hand dysfunction. The participants exerted maximal forces of the above mentioned five different upper limb activities. The determined regression equations describe relationship between body measures (body mass and body height) and values of maximal force for each of the considered types of upper limb strength. The statistical analysis showed relationship between force capabilities and body measures, in the considered upper limb activities. The study also reveal that correlations between body measures and force are similar in all analysed force activities, which means that each of the considered type of upper limb force can be a strength predictor. ***(Biol.Sport 21:369-378, 2004)***

Keywords: Maximal force - Hand grip – Pushing – Lifting – Pronation - Supination

Introduction

Maximal force measurements and analyses of relationship between strength and anthropometrical dimensions are widely applied in sport and rehabilitation. There are many factors, which influence the measured force. Even for the same experimental conditions different values of maximal force can be obtained according to different population of subjects, due to subjective factors like body mass, life style, occupation.

It is well-known that muscle strength increases proportionally with body size [16,20]. One of factors, which is strongly correlated with force exerted during

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handgrip is cross-section area of arm and forearm muscles [14]. Kellor *et. al.* [8], Mathiowetz *et al.* [15] and Su *et al.* [21] showed that maximum force depends on gender of examined population (for women it is from 30% to 59 % lower than for men). Maximum force is influenced also by age [8,22], occupation [5] and body posture [19].

In daily life, in sport settings and at the work place many different upper limb strength activities, imposing on the person necessity of exerting different types of force, can be enumerated. The most common upper limb strength activities are handgrip, lifting, pushing, pronation and supination.

Many publications have presented values of maximal handgrip force [4,6,11,12,18,21]. Also forces of pronation, supination, extension and flexion were examined by McGarvey *et al.* [13], Habes and Grant [3] and Kelly *et al.* [7] and study of maximal pull forces were performed by Netson and Kinnon [17]. However, for other upper limb strength activities as for example the moment of force of pronation and supination or the maximal force, which simulates the lifting of an object of determined mass less data is available.

There have been made several attempts to derive empirical equations for grip strength, associated with the subjects' anthropometric dimensions. Lunde *et al.* [10] derived equations to predict both dominant and non-dominant handgrip strength using height and mass, but these equations had relatively low coefficients of determination. Bohannon [1] on the basis of experimental study established the predictive equation expressing muscle strength in relation to body mass, gender and decade of age. Crosby *et al.* [2] proposed mathematical relationship between maximum grip strength and anthropometrical measurements (height and mass) as well as handiness and hobby demand.

The above mentioned study focused on handgrip force and expressed the force as a function of few factors influencing the force jointly. However, other upper limb strength activities may be of better correlation with body measures (height and body mass) than handgrip force. Also meaningful is regression equation expressing the relation between maximal force and one of the factors influencing the force (body height or body mass). Therefore the aim of the study was to analyse relationship between maximal force and body measures (mass and height) among the five types of strength activities (handgrip, lifting, pushing, pronation and supination) as well as comparison of relationship between maximal forces of various types of strength activities and body measures.

Material and Methods

Participants: Twelve right hand dominant men volunteered to participate in this study. All the subjects were healthy and without having any history of hand dysfunction (Table 1). The subjects were of 26 to 31 years of age (average 28.8), body height was from 172 to 185 cm (average 176.8) and body mass from 62 to 89 kg (average 73). The Physical University Ethics Committee approved the measurement procedure.

Table 1
Characteristics of subjects

	Age (years)	Body height (cm)	Body mass (kg)
GR	29	172	57
KT	28	180	77
KW	28	178	67
SJ	31	174	78
TA	32	185	89
TJ	29	176	66
TP	30	170	62
TT	30	172	73
ZI	26	176	73
RR	28	180	85
SW	27	182	79
ZC	28	177	71
Mean	28.8	176.8	73

Measurement procedure: Maximal forces for five different upper limb activities in twenty four upper limb postures have been examined, and this gives 120 protocols for each subject. For each protocol measurements were repeated twice. Experiments were randomised and performed in five series. Verbal encouragement was offered during the tests.

The measured types of upper limb strength activities were forces of lifting, pushing and handgrip as well as the torque of pronation and supination. Handgrip force was exerted by squeezing a sensor. The lifting force was directed vertically as it is exerted to the upper limb by the mass of the hold object. Pushing force is connected with the necessity of exerting a force to move an object or device horizontaly. The torque of pronation and supination demanded turning forearm.

Muscle strength was measured by dynamometer against which the participants exerted contractions of muscles in isometric tests. While exerting the maximal force for 3 seconds without jerking participants were in a sitting position. A handle held with a resisting rope exerted lifting and pushing force. Force was exerted to the handle in an upside direction for the lifting force or extending from the body in the case of the pushing force. The lifting force was directed vertically as the pushing force was directed parallel to the axis of the forearm. Measurement of grip strength was performed using equipment which consisted of a hand dynamometer. In measurements of the torque of pronation and supination a device was used which contained a dynamometer with a built in potentiometer connected with a gripped device.

Measurement equipment: The measurements of the force of lifting, pushing and handgrip as well as the torque of pronation and supination of the right upper limb were performed by a measuring system which consisted of the following parts:

- measurement devices (dynamometer or torquemeter),
- eight channel amplifier and 12-bit analogue-digital converter WT8RS,
- PC class computer (pentium processor),
- the especially developed software called CPS_v_2.0

Measurement devices were connected to an amplifier and analogue-digital converter and then by the serial cable to the computer. Software allowing for calculations and storing the data in the memory was developed. The developed CPS_v_2.0 software allowed for registering and graphically presenting the actual value of strength from the dynamometer and after the end of the test made it possible to show the measured value. Data of force and torque values exerted during exercises were stored in the computer memory. The maximal error of the method used to measure forces and torque is lower than 5%.

Results

Values of handgrip, lifting or pushing force for each of 12 participants in twenty four upper limb postures (288 measurements) are presented in Fig. 1 and for pronation and supination torques in Fig. 2.

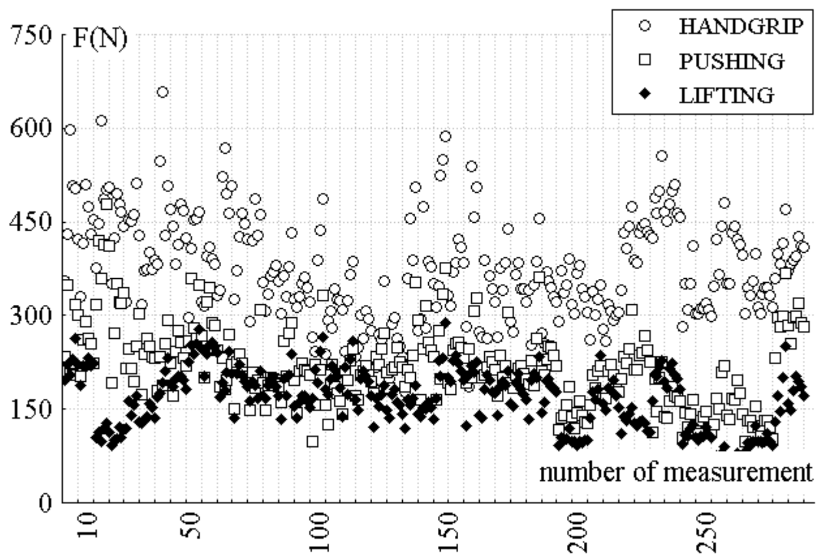

Fig. 1
Values of handgrip, pushing and lifting force for each of the performed measurements

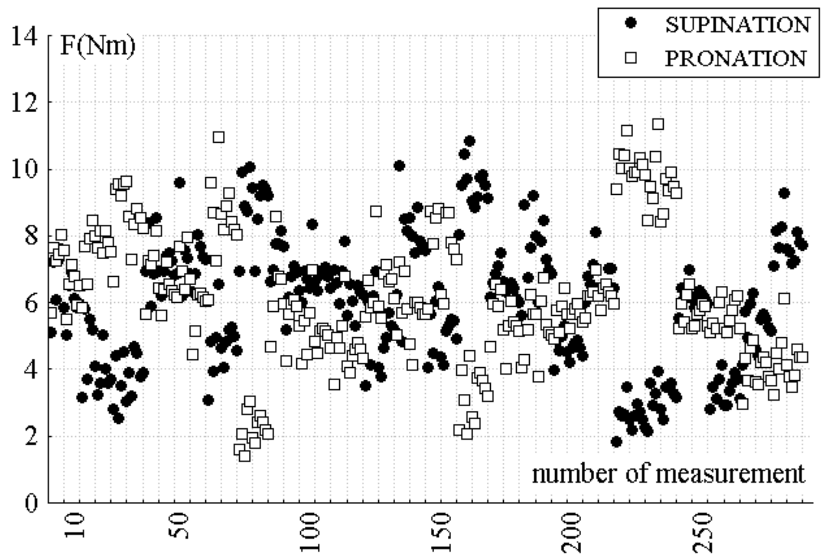

Fig. 2
Values of torgue of pronation and supination for each of the performed measurements

Values of force differed according to the upper limb posture for each type of upper limb strength activity. The mean values and standard deviation of maximal forces and torques for all the five analysed upper limb activities are presented in Table 2.

Table 2
Mean values and standard deviation of the measured force

Type of force		Mean value	Standard deviation
Handgrip	(N)	376.38	82.546
Pushing	(N)	217.48	64.278
Lifting	(N)	166.60	48.109
Supination	(Nm)	6.00	1.919
Pronation	(Nm)	6.15	1.998

Comparing the lifting, pushing and the handgrip force, the highest values occurred for the handgrip force and the lowest for the lifting force. The values of the pronation torque are slightly lower than the supination torque values. Ratio of correlation and probability level between the five types of force are presented in Table 3.

Table 3
Correlation coefficients and probability levels between force and torque values of the five types of upper limb activities

	SUP	PRON	PUSH	LIFT
HAND	-0.111	0.482	0.438	0.263
	P=0.061	P=0.000	P=0.000	P=0.000
SUP		-0.566	0.263	0.477
		P=0.000	P=0.000	P=0.000
PRON			0.285	0.139
			P=0.000	P=0.384
PUSH				0.445
				P=0.000

In eight out of ten cases correlation between values of forces of upper limb strenght are statistically significant. Not significant differences were obtained between pronation and lifting and between supination and handgrip. There is inverse, statistically signifficant correlation in case of pronation and supination.

Values of correlation coefficient and probability levels between body mass or body height and maximal force or torque are presented in Table 4.

Table 4
Correlation coefficients and probability levels between force and torque values and body mass

	HAND	SUP	PRON	PUSH	LIFT
BODY	0.378	0.257	0.245	0.420	0.332
MASS	P=0.000	P=0.000	P=.000	P=0.000	P=0.000
BODY	0.340	0.209	0.205	0.351	0.255
HIGHT	P=0.000	P=0.0001	P=0.0002	P=0.000	P=0.0003

In all cases there are statistically significant correlation between maximum force and body mass.

For handgrip, pushing and lifting correlation coefficients between maximal force values and body measures are higher than for pronation and supination. Correlation coefficient between handgrip force and body mass is only slightly higher than correlation coefficient between pushing force and body measures. It means that pushing force can be as good calculated on the basis of body measures as handgrip force.

The regression equations express maximal force as a function of body mass and body height are presented in Fig. 3. Figure presents also values of force of handgrip, lifting and pushing as well as torque of pronation and supination in relation to values of body measures (mass or height).

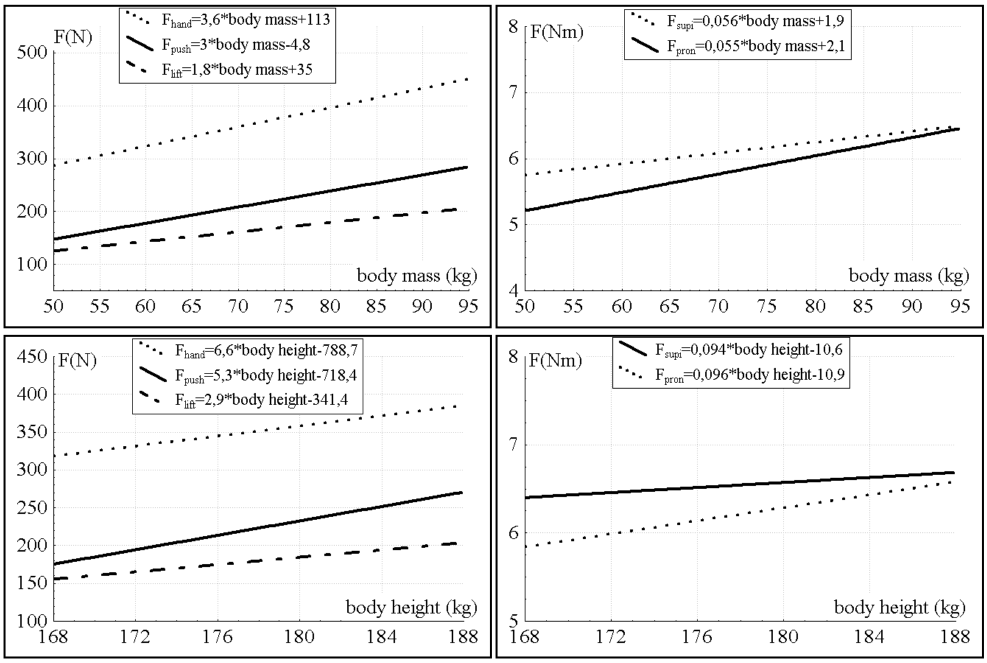

Fig. 3
Values of handgrip, lifting and pushing forces as well as torques of pronation and supination calculated by regression equations in relation to body measures (weight or height)

Discussion and Conclusion

The obtained, on the basis of experimental study, maximal forces or torques values allowed for elaboration of regression equation expressing maximal force or torque as a function of body measures (mass and height). Maximal forces for a specified upper limb posture can facilitate norms which can be useful for the purposes of sport, therapy, ergonomics. The study has proved that the type of upper limb strength activities influence the maximal value of the exerted force, which means that this factor is meaningful. However, analysis showed in most of cases correlations between values of different types of forces.

The study also proved that handgrip force is not the only measure of strength capabilities which can be expressed by body measures like body mass or body height and similarity of values of correlation coefficients evidence that forces of pushing and lifting or pronation and supination torques may be as well approximated by handgrip force.

Correlation coefficients between force values and body measure values demonstrated correlation, however, not very strong. It means that application of the assessment of strength capabilities on the basis of body measures is limited. However, developed regression equations allow for calculating maximal forces or torques as a function of body mass or body height as well as the type of upper limb strength activities and the developed relationship allows to estimate force on the basis of body measures without necessity of measurements, which in some cases gives a good tool for trainers, therapists as well as designers of work places.

References

1. Bohannon R.W. (1997) Reference values for extremity muscle strength obtained by hand-held dynamometry from adults aged 20 to 79 years. *Arch.Phys.Med.Rehabil.* 78:26-32

2. Crosby C.A., M.A.Wehbé, B.Mawr (1994) Hand strength: normative values. *J.Hand Surgery* 19A:665-670

3. Habes D.J., K.A.Grant (1997) An electromyographic study of maximal torques and upper extremity muscle activity in simulated screwdriving task. *Int.J.Ind.Ergonomics* 20:339-346

4. Hallbeck M.S., D.L.McMullin (1993) Maximal power grasp and three-jaw chuck pinch force as a function of wrist position, age, and glove type. *Int.J.Ind.Ergonomics* 11:195-206

5. Josty I.C., M.P.H.Tyler, P.C.Shewell, A.H.N.Roberts (1997) Grip and pinch strength variations in different types of workers. *J.Hand Surgery* 22B:266-269

6. Kattel B. P., T.K.Fredericks, J.E.Fernandez, D.C.Lee (1996) The effect of upper extremity posture on maximal grip strength. *Int.J.Ind.Ergonomics* 18:423-429

7. Kelly B.T., W.R.Kadrmas, D.T.Kirkendall, K.P.Speer (1996) Optimal normalization tests for shoulder muscle activation: An electromyographic study. *J.Orthop.Res.* 14: 647-653

8. Kellor M., J.Frost, N.Silberberg, I.Iversen, R. Cummings (1971) Hand strength and dexterity. *Am.J.Occup.Ther.* 25:77-83

9. Lamoreaux L, M.M.Hoffer (1995) The effect of wrist deviation on grip and pinch strength. *Clin.Orthop.Relat.* R 3145:152-155

10. Lunde B.K., W.D.Brewer, P.A.Garcia (1972) Grip strength of college women. *Arch. Phys.Med.Rehabil.* 53:491-493

11. Marley R.J., R.R.Wehrman (1992)Grip strength as a function of forearm rotation and elbow posture. In: Procceeding of the 36th Annual Meeting of the Human Factors and Ergonomics Society, Atlanta, pp. 791-795

12. Marley R.J., T.S.DeBree, R.Wehrman (1993) The effect of wrist, forearm and elbow posture on maximal grip strength. 2nd Industrial Engineering Research Conference. Proceedings. Los Angeles, pp. 525-529

13. McGarvey S.R., B.F.L.J.Morrey, K.N.Askew (1984) An reliability of isometric strength testing. *Clin.Orthop.Related Res.* 185:301-305

14. Martin S., G.Neale, M.Elia (1985) Factors affecting maximal momentary grip strength. *Hum.Nutr.: Clin.Nutr.* 39C:137-147

15. Mathiowetz V., N.Kashman, G.Volland, K.Weber, M.Dowe, S.Rogers (1985) Grip and pinch strength: Normative data for adults. *Arch.Phys.Med.Rehabil.* 99:69-72

16. Nevill A.M., R.L.Holder, A.Baxter-Jones, J.Round, D.A.Jones (1998) Modeling developmental changes in strength and aerobic power in children. *J.Appl.Physiol.* 84:963-970

17. Netson S., M.Kinnon (1998) Isometric pull forces in the sagittal plane. *Appl. Ergonomics* 29:319-324

18. O'Driscoll S.W, E.Horii, R.Ness, T.D.Cahalan, R.R.Richards (1992) The relationship between wrist position, grasp size, and grip strength. *J.Hand Surgery* 17A: 169-177

19. Roman-Liu D. (2003) Maximum handgrip force in relation to upper limb posture A Meta Analysis. *Am.Ind.Hygiene Assoc.J.* 64:609-617

20. Round J.M., D.A.Jones, J.W.Honour, A.M.Nevill (1999) Hormonal factors in the development of differences in strength between boys and girls during adolescence: a longitudinal study. *Ann.Hum.Biol.* 26:49-62

21. Su C, J.Lin, T.Chien, K.Cheng, Y.Sung (1994) Grip strength in different positions of elbow and shoulder. Grip strength as measured by the Jamar dynamometer. *Arch. Phys.Med.Rehabil.* 75:812-815

22. Thorngren K.G., C.O.Werner (1979) Normal grip strength. *Acta Orthop.Scand.* 50:255-259

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