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Impact of Muscle Strength and Sport Technique on Throwing Distance of Balls of Various Weights with a Dominant Arm

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Abstract The respondent sample for researching the impact of force, strength and sport technique on the throwing distance of balls of various weights (a 350 g handball, an 800 g handball and 3 kg handball) with a dominant arm was composed of 54 male members of youth handball school, aged between 16 and 17. In order to estimate force and strength, 11 tests were used – seven dynamometer ones used to measure the force of musculature activated during the throw (back, stomach, inner rotators of the shoulder joint and hand flexor muscles) and four repetitive maximum tests to estimate the absolute strength of those muscles (*Bench Press*, *Shoulder Press*, *Pull Over* and *Lat Machine*). Three experts estimated the level of handball technique during a session of handball tossing and catching in pairs of two. In order to estimate the sample homogeneity, the respondents were measured for body mass and height to obtain a body mass index (BMI). Regression analysis (*Stepwise* model) was used to estimate an impact of myogenic abilities and technique on throwing distance. It was established that with an increase of external resistance (throwing increasingly heavier balls) the role of force increases with a proportional decrease of impact of technique. Body mass was the most stable predictor of throwing length of any kind of ball. It existed in all regression models and most parameters of force and strength have indirectly affected dependable variables through it. The next most frequent predictor was handball technique. It showed to be significant during the use of two lighter balls, i.e. overcoming lesser external resistance and it was not present in the regression model for predicting the throwing length of the heaviest ball. Only inner rotators in shoulder joint were found to have a direct impact on throwing length, independent of body mass. It was found that the use of balls heavier than handball (up to 800 g) does not only represent a form of dynamic strength training, but that it can also be applied as a specific model of proprioceptive training for improving the handball technique.

Keywords Force, Strength, Sport Technique, Ball Throwing, Handball, Regression Models

1. Introduction

Numerous situations require athletes to confront external resistance, i.e. to overcome strong external forces. Weight lifting is a typical example where the result depends mostly on the lifter's strength (naturally, not exclusively on it). In sport games (football, basketball, handball...), competitors face the need to overcome the opponent's physical resistance, whether in a duel, by a higher jump or a quicker contraction during passing and shooting. External conditions result in the force sometimes developing slowly and sometimes very rapidly. This is the case with throwing objects of various weights that are sometimes relatively light (such as handball, basketball or rugby ball) and sometimes very heavy (shot put or hammer throw in athletics). Even in sports characterised by players hitting the ball between one another (volleyball or tennis), dynamic stereotypes almost identical to throwing movements are recognised. Even though in volleyball, for example, catching the ball is not allowed, serving and spiking technique have the same technical phases as handball or javelin throwing. All of these phases, regardless of whether they entail throwing or hitting the ball back, have similar characteristics and include analogous musculature, both in the topographic-functional sense (agonists, synergists, antagonists and stabilisers) and in the load regime.

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The primary source of differences between the cited dynamic stereotypes is the weight of the equipment (ball, javelin, racquet...). The biomechanical analysis of movement of certain kinetic chains shows that muscles develop greatest strength in maximum speed movements (under realistic circumstances), but with moderate load, such as arm movement in handball [1-3]. Apart from the strength and force, the sporting result (such as throwing distance) is also greatly affected by the quality of technique [4-11]. It is not uncommon that very muscular persons are unable to throw a ball as far as, for example, very gracile handball players, who lift far smaller weights during strength exercises in gyms, when practically engaging the same muscle groups during the throw. This raises an interesting question about the share of strength and force on the one hand and sporting technique on the other in the achieved result (in this research, more concretely, on throwing balls of various weights). Increase of muscular strength used in throwing movements does not automatically signify a longer throw, as shown by empirical studies realised with different throwing variants [12-15]. Respondents with better throwing technique have usually had longer throws, which practically indicated a greater force of throw (most often a shot). Empirical studies yielded various regression models that explained the specific impact of muscle strength and sport technique on throwing length [16-18]. The aim of this research is precisely to quantify the partial impact of strength and technique on the throwing distance when using one (dominant) arm.

A specific relation between muscle strength and sport technique is observed in everyday movements performed with dominant and non-dominant extremities. Analysis conducted during the performance of a movement with a weaker arm, in comparison with the same movement using a dominant arm, indicate not only the decrease of sport efficiency, but also the change of regression laws. Wang [19] has observed that there is a significant variability of impact of sport technique and muscle strength on shooting or hitting force when performed with a dominant and weaker arm, e.g. in baseball or tennis. The literature also cites experiments in which no significant differences were established between muscle capabilities (primarily absolute strength) of dominant and non-dominant extremities [20-24]. In these papers, apart from the objective dynamometric indicators of uniformity of analogous musculature of extremities on different sides, subjective respondents' feelings were registered regarding the strength of stronger and weaker extremities. It has been the case many times that the objective strength indicator and the subjective respondents' feelings were different. Despite the absence of significant differences in dynamometry, the respondents have regularly reported their dominant extremity as the stronger of the two. The mentioned information is of importance to this study, too, seeing as it indicates a nervous dependence of myogenic abilities and justifies the need to explore the relation between sport technique, as a typical neurogenic (coordination) property, and myogenic abilities of people.

2. Method

2.1. Study Design

The research was realised as an empirical study of transversal character analysing the impact of muscle strength and quality of handball technique on throwing distance of three balls of various weights with a dominant arm (a 350 g handball and two heavier balls of 800 g and 3 kg, respectively). The respondent sample was composed of 54 healthy young male persons, aged 16 to 17. All of them were members of the youth handball school from the Bačka Palanka municipality. The main criterion during the sample creation was that of each respondent having spent at least two years in the training process. The respondent sample was, according to the criterion of the competitive level, a heterogeneous one, seeing as it included both those talented boys who play for the youth national team of Serbia, as well as those who were not standard players even in their own clubs. In this way, variability is achieved needed for observing constancy of impact of the level of handball technique on the handball throwing distance.

The respondents were measured for basic anthropometric dimensions (height and body mass), from which their body mass indexes (BMI) were derived. After that, assessment of quality of handball technique was conducted, followed by the measurement of throwing distances with balls of various weights. On the next day, the dynamometric method was used to measure the respondents' hands and those muscle groups whose activity dominates in one-arm throwing movements and which could be realistically presumed to affect shot strength (inner rotators of shoulder joint, elbow joint extensors, torso flexors and extensors). After dynamometric tests, 1RM were assessed by using four classical weight-lifting exercises that engage muscle groups analogous to dynamometric tests, but also in the throwing movement: (1) *Bench Press*, (2) *Shoulder Press*, (3) *Pull Over* and (4) *Lat Machine*.

Collected data was processed by descriptive and statistical procedures, using the Portable IBM SPSS v.19 application. Seeing as all variables were shown minimally in the form of an interval scale (most of them proportional), central and dispersion parameters were determined for each item. The impact of force and strength, body dimensions and handball technique on the measured throwing distances of three balls of various weights was quantified by means of the *Stepwise* model of regression analysis that enables a gradual exclusion of initial predictors that have no significant impact on the dependent variable. That is how three optimal regression models were obtained, explaining partial impact of muscle strength and sport technique on the distance of measured throw.

2.2. Instruments and Measurement Technique

Measurements of body dimensions were conducted in mornings, using *Tanita BC-418MA* electronic anthropometric weighing scales. Height was measured with the precision of 1 cm and body mass with that of 0.5 kg.

Dynamometer tests were conducted in positions that allowed for isolated isometric strain of the relevant muscle groups. Maximum force value was measured for the following muscle groups: torso extensors (back musculature), torso flexors (stomach musculature), inner rotators in shoulder joint during one-arm and two-arm load. Every respondent had two attempts and better of the two results was used for statistical processing. Latest electronic equipment was used: for hand dynamometry – a *Baseline Electronic* (*Smedly Hand Dynamometer 200 lb. W54654*) and for dynamometry of other muscle groups an *ISO Control* mobile dynamometer from the *Globus Tesys 1000* equipment system. Force tests were conducted with the precision of 1 N.

During the testing of 1RM, the respondents were required to lift a certain load a maximum number of times (until failure), with the number of repetition being under ten. Determination of repetitive maximum was preceded by a warmup series in which a mid-sized weight was lifted. In each successive series, weights were progressively increased until reaching an optimal testing weight. In most respondents, failure set in during the third series, between the fourth and sixth repetition. 1RM value was calculated on the basis of the number of repetitions preceding failure, by multiplying the increased weight with adequate coefficients: 2RM x 1.07; 3RM x 1.1; 4RM x 1.13; 5RM x 1.16; 6RM x 1.2; 7RM x 1.23; 8RM x 1.27; 9RM x 1.32 i 10RM x 1.34 [25]. Measurement results were shown in kiloponds, with the precision of 2.5 kp.

The quality of throwing technique was evaluated by three handball experts (three top-level coaches) who watched the ball throwing and catching in pairs and gave their ratings on a 1 to 10 scale. Pori, Bon and Šibila [6] have suggested this procedure. They found high accordance between the expert assessment and kinematic models of handball techniques assessment. These authors believe that the numerical score of three observers sufficiently reliable method for assessing the quality of sport technique. The final grade, used for statistical data processing, was formed after consultations among evaluators. During the technique test, the respondents passed the handball between one another for five minutes, first standing and then moving, at a distance of 8 to 10 m.

After passing the ball in pairs, which also served as a warm up, the respondents began throwing the ball as far as possible, using their dominant arm. Throwing was performed from the sport, with a maximum swing, with every respondent independently deciding on the shot trajectory. The throwing length was measured with a measuring tape and was determined with the precision of 0.1 m. Each respondent took two throws of three balls of different weights and the better of the two results was taken for statistical processing. First they threw a standard handball of 350 g, then a somewhat heavier ball of 800 g and then the medicine ball of 3 kg.

3. Results

After an insight into descriptive parameters calculated for all morphological variables (Table 1), it was established that the sample was highly homogenous. It was markedly dominated by respondents with normal body composition ($22 \leq BMI \leq 27$), while the number of those with an insufficient or excessive body mass was negligible.

Dynamometric tests revealed expected values of force for isolated muscle groups, within the values of previous research. The same is true of absolute strength indicators (1RM). Greatest values were recorded in testing the force of back musculature, and the smallest in testing shoulder joint rotators. Greater values of absolute strength were recorded in movements that engaged a larger muscle mass of respondents (*Bench Pres* and *Lat Machine*), while smaller values were obtained in *Shoulder Press* and *Pull Over* tests (Table 1). In most tests (dynamometer and RM), very homogenous results were obtained, which was expected, seeing as the respondents were of the same age and very similar in terms of body dimensions.

Based on expert evaluations, a relatively low level of handball technique of respondents was recorded, which is logical, considering the fact that respondents were youth players, who still have not automatized their movements, most of them facing coordination issues due to adolescent body changes. In terms of the technical level, the sample was less homogenous in comparison with anthropometric and myogenic characteristics. With an increase of ball weight, the throwing distance of all respondents was noticeably decreased, as expected (Table 1).

By analysing the impact of the initial system of predictor variables (force, strength and throwing technique) on independent variables (throwing distances of three different balls), a statistically significant impact was confirmed only in handball throw, (Table 1), while in throwing two heavier balls (800 g and 3 kg) the entire system had no significant impact (Tables 2, 3 and 4). This justified the use of the *Stepwise* model of regression analysis that finally resulted in a system of predictors suitable for quantifying the partial share of strength, technique and anthropometric dimensions, by gradually eliminating independent variables. Overall, body mass showed to be the most stable predictor of throwing distance of any ball. It existed in all three final regression models. By all odds, most parameters of force and strength have indirectly affected dependent variables through it, especially in movements in which the largest muscle groups were active (torso flexors and extensors, back and stomach musculature). After body mass, included in all three final regression models, the next most frequent variable that was given the status of a significant predictor was – handball technique. It proved to be significant during the use of two lighter balls (of 350 and 800 g), i.e. overcoming smaller external resistance. Technique was not present only in the model obtained for throwing the heaviest ball (3 kg).

A small number of variables of force and strength had a direct impact on measured throwing distances, independent of body mass. The most influential muscle group were found to be inner rotators of the shoulder joint that were present in two of the three regression models obtained for handball throwing and the heaviest balls. This muscle group was tested in both load regimes – isometric (dynamometric test) and dynamic (*Pull Over*). Engaging rotators of both arms in the dynamic regime, which is primarily associated with expression of strength, showed to be significant only during throwing of the easiest ball, while during throwing of the heaviest one, dynamometric results were much more significant. This confirms the theoretical standpoint that with an increase of external resistance, the role of force grows, with a proportional decrease of impact of strength.

Table 1. Descriptive parameters calculated for anthropometric variables of respondents

Variables	N	**Mean**	Std. Deviation	Std. Error	Min	Max
Body Height (m)	54	**1.825**	.0618	.0084	1.71	1.96
Body Mass (kg)	54	**79.611**	9.3711	1.2752	62.0	106.0
BMI (kg/m^2)	54	**23.868**	2.2641	.3081	18.12	29.36
Hand dynamometry (N)	54	**437.27**	80.244	10.920	269.78	588.6
Rotators of stronger arm (N)	54	**240.35**	80.806	10.996	98.10	392.4
Rotators of both arms (N)	54	**403.03**	103.665	14.107	137.34	568.98
Back dynamometry (N)	54	**1185.65**	194.086	26.412	696.51	1569.6
Stomach dynamometry (N)	54	**369.24**	138.050	18.786	112.82	711.23
Bench Press – RM1 (kp)	54	**75.600**	15.6996	2.1364	45.20	116.0
Shoulder Press – RM1 (kp)	54	**56.456**	10.0209	1.3637	33.90	87.10
Pull Over – RM1 (kp)	54	**40.548**	6.9322	.9433	22.00	59.40
Lat Machine – RM1 (kp)	54	**70.259**	11.5173	1.5673	44.37	98.98
Throw technique assessment	54	**6.7**	1.327	.181	5	9
Handball throw (m)	54	**36.176**	4.5241	.616	26.3	46.4
800 g ball throw (m)	54	**19.678**	3.4505	.469	14.3	28.8
3 kg ball throw (m)	54	**10.431**	1.2896	.175	8.0	13.0

Table 2. Coefficients obtained by applying the *Stepwise* model of regression analysis in which the dependent variable was the **handball throw distance** (Only parameters for the initial and the last steps of regression analysis were shown)

		Unstandardised Coefficients		Standardised		
Model	Predictors	**B**	Std. Error	***Beta***	**t**	*Sig.*
Initial	*Constant*	18.506	15.208		1.217	*.231*
	Body Mass	.276	.067	.571	4.115*	***.000***
	Body Height	-6.096	9.346	-.083	-.652	*.518*
	Hand dynamometry	.008	.007	.150	1.182	*.244*
	Stronger arm rotators	.006	.008	.112	.796	*.431*
	Rotators of both arms	.001	.007	.027	.182	*.857*
	Back dynamometry	-.006	.003	-.267	-1.887	*.066*
	Stomach dynamometry	.006	.004	.175	1.368	*.179*
	Bench Press	-.023	.052	-.079	-.438	*.664*
	Shoulder Press	-.204	.073	-.452	-2.808*	***.008***
	Pull Over	.272	.098	.417	2.772*	***.008***
	Lat Machine	-.017	.052	-.044	-.333	*.741*
	Technique rating	1.467	.384	.430	3.825*	***.000***
Final	*Constant*	8.567	4.631		1.850	*.070*
	Body Mass	.229	.051	.475	4.513*	***.000***
	Pull Over	.288	.074	.442	3.880*	***.000***
	Technique rating	1.345	.339	.394	3.967*	***.000***

Table 3. Coefficients obtained by applying the *Stepwise* model of regression analysis in which the dependent variable was the **throwing distance of a 800g ball** (Only parameters for the initial and the last steps of regression analysis were shown)

Model	Predictors	Unstandardised Coefficients		Standardised	t	Sig.
		B	Std. Error	***Beta***	**t**	*Sig.*
Initial	*Constant*	-13.655	15.230		-.897	*.375*
	Body Mass	.097	.067	.263	1.442	*.157*
	Body Height	14.708	9.359	.264	1.571	*.124*
	Hand dynamometry	-.002	.007	-.036	-.216	*.830*
	Stronger arm rotators	-.001	.008	-.015	-.081	*.936*
	Rotators of both arms	-.003	.007	-.095	-.481	*.633*
	Back dynamometry	-.001	.003	-.043	-.232	*.818*
	Stomach dynamometry	.000	.004	-.008	-.048	*.962*
	Bench Press	.022	.052	.102	.433	*.668*
	Shoulder Press	-.079	.073	-.230	-1.090	*.282*
	Pull Over	.072	.098	.144	.731	*.469*
	Lat Machine	-.052	.052	-.174	-1.003	*.322*
	Technique rating	.806	.384	.310	2.097*	***.042***
Final	*Constant*	4.810	4.316		1.114	*.270*
	Body Mass	.115	.046	3.11	2.486*	***.016***
	Technique rating	.858	.325	.330	2.637*	***.011***

Table 4. Coefficients obtained by applying the *Stepwise* model of regression analysis in which the dependent variable was the **throwing distance of a 3kg ball** (Only parameters for the initial and the last steps of regression analysis were shown)

Model	Predictors	Unstandardised Coefficients		Standardised	t	Sig.
		B	Std. Error	***Beta***	**t**	*Sig.*
Initial	*Constant*	2.335	5.561		.420	*.677*
	Body Mass	.051	.025	.367	2.061*	***.046***
	Body Height	.488	3.418	.023	.143	*.887*
	Hand dynamometry	.004	.003	.268	1.644	*.108*
	Stronger arm rotators	.002	.003	.131	.724	*.473*
	Rotators of both arms	.002	.002	.145	.756	*.454*
	Back dynamometry	-.001	.001	-.089	-.488	*.628*
	Stomach dynamometry	.001	.002	.059	.357	*.723*
	Bench Press	.004	.019	.045	.195	*.846*
	Shoulder Press	-.010	.027	-.075	-.364	*.718*
	Pull Over	-.020	.036	-.106	-.551	*.584*
	Lat Machine	-.004	.019	-.033	-.194	*.847*
	Technique rating	.283	.140	.291	2.019*	***.050***
Finale	*Constant*	4.904	1.453	/	3.375*	***.001***
	Body Mass	.052	.017	.381	3.009*	***.003***
	Rotators of both arms	.003	.002	.261	2.188*	***.033***

4. Discussion

Even though anthropometric dimensions (body mass and height and body mass index) were registered in this research primarily with the aim to estimate the sample homogeneity, it turned out that body mass had one of the key effects on all dependent variables – throwing distances of three balls of various weights. Apart from the dependent ones, body mass showed a very strong relation to most variables of force and strength. This relation was crucial to decrease the partial impact of indicators of force and strength on dependent variables. These results correspond to previous studies [26-28] in which established a major influence of body size to all tests of muscle strength. A very small number of tests of force and strength was present in the final regression models. Force and strength apparently showed their impact on dependent variables indirectly, through body mass. Weak impact of strength and power to specific human movements was found in some previous studies [29, 30].

A direct impact on measured throwing distances, independent of body mass, was shown only by shoulder joint internal rotators. The importance of internal rotator on quality of one-arm throwing the ball evidenced in some previous studies carried out with handball [5, 10, 15, 31, 32]. The regularity of work of this synergic muscle group was indicated by results obtained in different load regimes – isometric (dynamometer test) and dynamic (*Pull Over*). Engaging the rotators of both arms in the dynamic load regime, which is theoretically primarily associated with expression of strength, was statistically significant for throwing the easiest ball, i.e. when overcoming small external resistance. During the throwing of the heaviest ball, the role of *Pull Over*, as the predictor in the regression model was taken by a dynamometric test of the same muscle group. This shows that during greater external resistance, the working muscles increasingly transfer from the dynamic to isometric load regime, i.e. that the role of force increases and that of strength decreases with the increase of resistance.

Domination of shoulder joint rotator muscles in terms of prediction of results of one-arm throw was expected and completely logical. Namely, biomechanical analysis of this movement can easily confirm that these are the muscles that are active during the performance of the throwing technique, from the swing and ejecting to swing-back, all in the dynamic load regime. These confirmed the biomechanical analysis conducted in previous research [10, 33]. This confirms one of the important training laws – when choosing additional exercises aimed at improving sport performance, it is most efficient to use movements as analogous as possible to those found in the play. It can be claimed, on the basis of this research, that *Pull Over* should occupy a very important place in the strength training of handball players.

The absence of handball technique from the final regression model designed for an estimate of throwing distance of the heaviest ball (a 3 kg ball), should not be interpreted one-sidedly, i.e. should not be used to claim that technique has no significant impact on results of throwing of heavy balls. This information could rather indicate the irrationality of using handballing technique in throwing heavy objects and point to the need to apply more efficient technical models, such as shot put. Practically, it would be more rational to push all heavier objects, supporting them with the body in order to create optimal biomechanical conditions for transferring the entire kinetic energy of the body onto the object, and not just the movement quantity of the hand. Every piece of sporting equipment requires a biomechanically justified throwing technique. It appears that it is irrational to use handballing technique for throwing heavy objects and equipment. In athletics, for example, the one-armed (handball) throwing movement is used only for javelin, as the lightest piece of throwing equipment.

No increase of ball weight changed the share of force and strength on the one hand and sporting technique on the other. Using an 800 g ball did not introduce any significant change of relation between myogenic capabilities and sporting technique. Practically, only by applying a great external resistance, i.e. using the ball several times as heavy as the one used in play (handball) did that relation break. The share of technique was not only diminished, but completely lost instead. Similar results were obtained Van Muijen [17], while Arias [34] found that young players achieve better accuracy with less weight balls.

Apart from the fact that body mass was the most stable predictor of distance in all variants of throw, the obtained regression models indicate that the throwing technique had a somewhat greater impact than myogenic capabilities. The greatest difference in favour of technique was observed during a realistic handball throw, when a real 350 g handball was used. Where the exact line is where the relation of myogenic capabilities and sport technique drastically changes – remains unknown. This observation also contains the basic flaw of this research. In order to establish precisely the zone of external load in which the impact of technique significantly diminishes, several balls of different, finely graded weights, should have been thrown. It would have been justified to ask of the respondents to throw at least one or two balls of different weights, such as those of 1.5 or 2 kilogrammes. This would probably yield regression models that would indicate a gradual decrease of the share of technique.

From the aspect of sport practice, regression models established for throwing an 800 g ball proved to be very interesting. Although one could have expected a trend of an increased impact of force on the throwing distance, with a simultaneous decrease of impact of technique, upon increasing external resistance (using a heavier ball) – that did not happen. On the contrary, the final regression model did not at all feature force and strength, while body mass and handballing technique were the only two significant predictors. These data give ground to the presumption of useful effects of using balls heavier than handball, but probably not heavier than 800 g. Working with heavier balls (such as those of 500, 600 or 800 g, for example) can apparently be recommended to handball practice as an efficient training means. This can probably be explained by a greater engagement of proprioceptive mechanisms, primarily the mechanoreceptors in the shoulder and elbow joints. It appears that an 800 g ball, generally extensively used in handball training, primarily to increase strength, can even be recommended as an efficient tool for improving technique. Its weight is, apparently, a stimulus strong enough for a significantly higher excitation of mechanoreceptors, without also being too great an external load that would hamper technique, i.e. the functional synergy of musculature used. Working with 800 g medicine balls is thus not only a form of dynamic strength training, but can also be recommended as a model of proprioceptive training for technique improvement.

5. Conclusions

It is not realistic to forecast a mathematically precise role of technique and myogenic capabilities (force and strength) in a one-arm ball throw, but it is more justified to analyse their specific and relatively equal impact on sport performance. In programming of sport training, it is necessary to pay significant attention to both anthropomotoric fields. Whether there is a greater space for improvement of sport performance in the field of force and strength or in that of coordination – still remains a sensitive question. The coaches working directly with the athletes could give the best answer. A significant help could be found in regression models obtained in this research. The only sustainable, and hereby confirmed, regularity that defines the share of force and strength on the one hand and sport technique on the other during the forecasting of sport result is that the key determinant for quantifying their interrelation is the amount of external resistance. It was established that with an increase of external resistance, i.e. use of increasingly heavier balls, the role of myogenic capabilities generally increases, with a proportional decrease of impact of sport technique. The moment when the impact of throwing technique becomes inferior in comparison to the muscle strength is a reliable signal that it is necessary to look for a more biomechanically rational way of throwing.

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