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Section III – Sports Training

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Effect of 8 Weeks of Free-Weight and Machine-Based Strength Training on Strength and Power Performance

by

Klaus Wirth[1], Michael Keiner[2], Hagen Hartmann[3], Andre Sander[4]; Christoph Mickel[3]

The aim of this study was to evaluate the effectiveness of free-weight and machine-based exercises to increase different strength and speed-strength variables. One hundred twenty male participants (age: 23.8 ± 2.5 years; body height: 181.0 ± 6.8 cm; body mass: 80.2 ± 8.9 kg) joined the study. The 2 experimental groups completed an 8 week periodized strength training program that included 2 training sessions per week. The exercises that were used in the strength training programs were the parallel barbell squat and the leg press. Before and after the training period, the 1-repetition-maximum in the barbell squat and the leg press, the squat jump, the countermovement jump and unilateral isometric force (maximal isometric force and the rate of force development) were evaluated. To compare each group pre vs. post-intervention, analysis of variance with repeated measures and Scheffé post-hoc tests were used. The leg press group increased their 1-repetition-maximum significantly (p < 0.001), while in the squat group such variables as 1-repetition-maximum, the squat jump and the countermovement jump increased significantly (p < 0.001). The maximal isometric force showed no statistically significant result for the repeated measures factor, while the rate of force development of the squat group even showed a statistically significant decrease. Differences between the 2 experimental groups were detected for the squat jump and the countermovement jump. In comparison with the leg press, the squat might be a better strength training exercise for the development of jump performance.

Key words: *strength, power, diagnostics, squat, leg press.*

Introduction

Strength training-induced increases in speed strength seem indisputable (Arabatzi et al., 2010; Christou et al., 2006). Several longitudinal investigations have found increases in squat jump (SJ) and countermovement jump (CMJ) performance after strength training interventions using different training exercises (Arabatzi et al., 2010; Christou et al., 2006). In this context, different effectiveness of free-weight compared to machine-based strength training is often discussed (Luebbers and Fry, 2011; Lyons et al., 2010). In the comparison of the squat and leg press exercise, both exercises train nearly the same muscles of the lower extremities, but in some aspects they are different: the leg-press has less requirements concerning balancing the weight and therefore, less muscle activity contributes toward stabilization compared to the squat, however, the leg press allows more force to be applied in the linear path. Furthermore, the squat movement keeps the individual in an upright position, but the leg-press movement for

[1] - *Institute of Training and Sport, University of Applied Sciences Vienna Neustadt, Austria.*
[2] - *Swimming Federation of the State Lower Saxony, Hannover, Germany.*
[3] - *Institute of Sports Sciences, Department of Human Movement Science and Athletic Training, Johann Wolfgang Goethe-University, Frankfurt, Germany.*
[4] - *German Luge and Bobsled Federation, Berchtesgaden, Germany.*

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example with a 45° leg press is performed by the individual in a nearly supine position. Compared with the squat, the 45° leg press spares the last 45° extension motion in the hip and consequently the hip extensors are not trained in that range. The same issue can be applied to the seated leg press – dependent on the inclination of the back cushion. The seated leg-press movement also has a horizontal/vertical movement pattern, whereas the squat requires almost a vertical press. Therefore, the specific adaptations have to be considered (Wilk et al., 1996).

However, differences in effectiveness always have to be discussed in the context of the desired training goal. It is conceivable that a strength training exercise that is optimal for gains in muscle hypertrophy may not be ideal for the development of speed-strength. Different conditions may be required for an exercise to meet these two training goals. For a gain in the muscle cross-sectional area, training with high loads is necessary to create the required high tension on the muscle fibers (Fry, 2004). To maximize performance in speed-strength, neurophysiological adjustments are required, at least in the short term (Zaras et al., 2014). This means that the greatest possible number of motor units must be recruited and addressed simultaneously with a high innervation frequency in a short time window (Duchateau and Hainaut, 2003). However, these timely constraints are of minor importance for hypertrophy effects. Continuous improvements in speed-strength are generated via concurrent strength and power exercises in a periodized fashion over years of resistance training (Baker and Newton, 2008), whereby maximum strength is regarded as the basic quality for high speed-strength performance (Pearson et al., 2002). Therefore, it may be expected that an increase in maximum strength alone is a sufficient training stimulus for the development of speed-strength in moderately trained subjects (Baker, 2001).

Additionally, the way of testing maximal force production is of importance. In the context of force measurements in competitive sports as well as in preventive and rehabilitative settings, isometric measurements are often carried out and recommended (Balyzer et al., 2015; Marcora and Miller, 2000). Balyzer et al. (2015) stated for testing under isometric conditions that a high number of subjects could be evaluated in a short period of time and that it was a safe method for testing maximum strength. However, previous studies had only reported statistically moderate to strong relationships between multi-joint isometric tests and dynamic movements such as vertical jumps (Kawamori et al., 2006), shot put and weighted throw performance (Stone et al., 2003). The problem for competitive sports is that muscles or muscle groups are mostly trained dynamically, but the level of strength and/or the rate of force development are analyzed under isometric conditions. Such an approach engenders the issue of strength increases achieved in training exercises, which cannot be confirmed in the diagnostic test procedure (Hartmann et al., 2009). Numerous documented specific adaptations to strength training, in this case primarily joint angle and contraction type-specific adaptations, may explain this problem (Knapik et al., 1983; Paddon-Jones et al., 2001; Seger and Thorstensson, 2005). Therefore, there is a risk of evaluating training and therapeutic successes in an incorrect way. Consequently, problems arise for the interpretation of standard data in health care or competitive sports, if they were determined through isometric measurements. From this perspective, it is also important to examine to what extent the relationship between isometric and dynamic testing is affected by the selected weight training exercises.

The aim of the study was to determine how the selection of the training exercise influenced speed-strength performance during an 8 week training intervention. In addition, we analyzed to what extent an increase of maximum strength affected an independent maximum strength variable. Furthermore, correlations between tested variables were calculated.

Material and Methods

Participants

One hundred twenty students (aged: 23.8 ± 2.5 years; body height: 181.0 ± 6.8 cm; body mass: 80.2 ± 8.9 kg) of the Institute of Sports Science, Goethe University, Frankfurt, Germany, volunteered for the study. Each subject was informed of the experimental risks involved with the research. All subjects provided written informed consent to participate. The research design was approved by the institutional review board of the Institute of Sports Science, Goethe University, Frankfurt, Germany. The study was carried out with respect to the use of human subjects and according to the Declaration of Helsinki.

Design

The participants were divided into 3 groups. The 1st group (SQ) completed an 8 week strength training protocol using the parallel barbell squat (60–70° knee angle). The 2nd group (LP) followed the same training protocol, but using the leg press (45° leg press, 90° knee angle). The 3rd group (CON) constituted a control group and did not perform resistance exercise during the experiment.

Procedure

The pretest was performed 3 days after a familiarization test, which included the same tests in the same order. The same tests were carried out again 3 days after the last training session. The tests were realized in the order described below after a standardized warm-up. The warm up consisted of 5 min of submaximal cycling on an ergometer and 2 to 3 sets of moderate loaded squats with 6 repetitions each.

First, the SJ (test-retest reliability r = 0.87; $p < 0.05$), then the CMJ (test-retest reliability r = 0.94; $p < 0.05$) performance were measured (5 trials each) using a contact mat (Refitronic, Schmitten, Germany) that operates like a switch. The system only provides information on whether the mat is loaded or not. Therefore, flight time is measured and further, the jump height calculated ($\frac{gt^2}{8}$; g = the gravitational acceleration [9.81 $m \cdot s^{-2}$] and t = flight time). An error estimate can be found in Frick et al. (1991). The jumps were performed at a knee angle of 90° with the hands fixed at the hips. In the SJ, subjects were asked to hold a static position of the 90° knee angle for 2 s, before they jumped (without momentum). In the CMJ, subjects started in an upright position, then descended quickly to the 90° knee angle before they jumped. The correct movement execution was controlled visually by the investigators. The subjects had a rest period of 2 min between jumps.

Isometric maximum force (MIF) was determined using a legwork machine (BAG, Wolf, Germany, test-retest reliability r = 0.90; $p < 0.01$) in a seated position with a hip angle of 60° and a knee angle of 120°. In addition, the rate of force development (RFD; test-retest reliability r = 0.77; $p < 0.01$) was determined from the force-time curves. Subjects had 3 attempts with a rest period of 5 min between attempts. The joint angles were controlled via a goniometer. Subjects were further encouraged to produce maximum strength as fast as possible and to continue the efforts for 3 s. Therefore, we instructed them to build up maximal strength in an explosive fashion.

Preliminary studies for the BAG showed that the pressure load between the backrest (which is supported in the lower area of the back through several components made of steel) and the lumbar region of the back was considered very unpleasant, nearly painful, for the participants, when using both legs for testing. To avoid inhibitory influences (resulting from pain) on the development of speed-strength, a unilateral test was performed. The 120° knee joint angle was chosen as it represents a favorable position for the development of explosive force production (Hemmling, 1994). Larger angles would lead to lower maximum force values (Hemmling, 1994). In addition, based on preliminary studies, subjects described knee joint angles of 90° or less as unpleasant to painful.

Maximum dynamic strength was determined through the load of the one repetition maximum (1RM) in the squat or the leg press 15 min after determining MIF. The maximal load was determined in a series of 1RM. Determination of the 1RM was achieved within a maximum of 5 trials. Rest periods between attempts were at least 5 min. The criterion for a successful attempt in the squat was a trial in which the upper part of the knee musculature was parallel to the floor at the turning point and the leg was completely extended in the upright position. Attempts failed when the subjects rounded their back, lost the bar, or where not able to flex the knees to the desired depth. In the leg press (Rowe & Kopp, Oberursel, Germany), the load was lowered to a knee joint angle of 90°. Range of motion was monitored using a goniometer attached to a knee brace. Subjects wore the knee brace at their right knee. At the starting position (with both legs on the plate) a trigger was set. The test-retest reliability coefficient for the leg press was r = 0.96 ($p < 0.05$) and r = 0.92 for the squat ($p < 0.05$).

The training groups performed 5 sets of their 8-10 repetitions maximum (RM) during the first 3 weeks. Thereafter, training groups performed 5 sets of 6-8 RM in the 4th to 6th week, and 5 sets of 4-6 RM in the 7th and 8th weeks. Subjects were always allowed 5 min of rest between sets. The difference between the training groups was the selected exercise only (squat vs. leg press). Generally, bouncing the bar in the eccentric-concentric transition phase was not allowed. The subjects performed each set to momentary muscular failure in the last 2 repetitions of the targeted repetitions scheme (forced reps). The researchers provided spotting and strong verbal encouragement. If necessary, resistance was adapted by 2.5 – 10 kg for the next set or next training session for the subject to stay in the particular repetition scheme.

Statistical Analysis

Data were analyzed with SPSS 17.0. It was checked for normality using the Kolmogorov-Smirnov test. For all group comparisons and comparisons between pre- and post-intervention results, 2-factorial analyses of variance were performed using a repeated measures model. The Mauchly sphericity test was performed prior to ANOVAs. If sphericity was calculated as statistically significant, the Greenhouse-Geisser correction was used. When statistically significant F values were returned, the Scheffé's test was used for further post hoc analyses. Since different tests of maximum dynamic strength (squat and leg press) cannot be directly compared, the variation of maximum strength measures over the study period was analyzed using the t-test for paired samples. The correlation between the tested variables was calculated by the Pearson's product-moment coefficient. The level of significance for all statistical tests was set at $p < 0.05$. The relationships were classified as follows: 0 = no correlation, $0 < | r | < 0.2$ = very weak correlation, $0.2 \leq | r | < 0.4$ = weak correlation, $0.4 \leq | r | < 0.6$ = moderate correlation, $0.6 \leq | r | < 0.8$ = strong correlation, $0.8 \leq | r | < 1.0$ = very strong correlation, 1 = perfect correlation.

Results

The Kolmogorov-Smirnov test showed the data were normally distributed for all test variables. Furthermore, the homogeneity of variance between groups was confirmed using the Levene test for all variables. The anthropometric data are presented in Table 1.

The ANOVA with repeated measures showed, for both the maximum isometric force of the left leg (MIF L, $p > 0.05$) and the maximum isometric force of the right leg (MIF R, $p > 0.05$), no statistically significant result for the repeated measures factor. However, for both variables, a statistically significant result in the comparison of groups was found (MIF L: $p \leq 0.001$; MIF-R: $p \leq 0.001$). In both cases, statistically significant group differences between the CON and SQ groups (MIF-L: $p \leq 0.001$; MIF-R: $p \leq 0.001$) and between the CON and LP groups (MIF-L: $p \leq 0.001$; MIF-R: $p \leq 0.01$) were calculated. The results are presented in Table 2.

The ANOVA with repeated measures showed, for both the RFD of the left (RFD-L, $p \leq 0.05$) and the right leg (RFD-R, $p \leq 0.001$), a statistically significant result for the repeated measures factor. The results of the RFD are presented in Table 3. However, for neither variable a statistically significant result in the comparison of groups (RFD-L: $p > 0.05$; RFD-R: $p > 0.05$) was found. For both, the left and the right leg, a statistically significant decrease of the RFD was observed in the control group. In addition, the results of the SQ group showed a statistically significant decrease in the RFD.

The ANOVA with repeated measures showed, for both the squat jump (SJ, $p \leq 0.001$) and the countermovement jump (CMJ, $p \leq 0.001$), a statistically significant result for the repeated measures factor. For both variables, a statistically significant result for the group comparison was detected (SJ: $p \leq 0.001$; CMJ: $p \leq 0.001$). In both cases, statistically significant group differences were found for all 3 group comparisons ($p \leq 0.001$). The changes in performance in the SJ and the CMJ from pre- to post-intervention showed a statistically significant improvement in both variables in the SQ group and a statistically significant decrease in performance in the SJ in the CON group. The results are presented in Table 4.

The t-test for paired samples showed a statistically significant increase in maximum dynamic strength for both groups (SQ: $p \leq 0.001$; LP: $p \leq 0.001$). For the MIF-LR variables, the ANOVA with repeated measures showed a statistically significant result for the group comparison ($p \leq 0.001$), but no statistically significant result for the repeated measures factor ($p > 0.05$). Both training groups (SQ, LP) differed significantly from the control group (CON) in their performance increases ($p \leq 0.001$). The results are presented in Table 5.

The correlations are presented in Tables 6 and 7. The correlations in the SQ group were mostly statistically significant. Only the correlations between the RFD-L and the SJ as well as between the RFD-L and the CMJ were not statistically significant.

In the LP group all correlation coefficients reached the level of significance.

Table 1

Anthropometric data of the participants

		Age (y)		Body height (cm)		Body mass (kg)	
	N	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
CON	37	25.1	2.1	181.0	5.7	78.2	8.5
SQ	43	23.7	2.7	181.7	7.5	81.6	9.8
LP	40	23.8	2.3	180.1	7.0	80.5	8.1

$\bar{x}$ = mean values; SD = standard deviations; y = years; cm = centimeters; kg = kilogram; CON = control group; SQ = squat group; LP = leg press group

Table 2

Means, standard deviations and changes in maximum isometric force (N) from pre- to post-test

	MIF-L					MIF-R				
	T1		T2			T1		T2		
	$\bar{x}$	SD	$\bar{x}$	SD	%	$\bar{x}$	SD	$\bar{x}$	SD	%
CON	2127	565	1979	471	-5.7	2147	510	2030	484	-4.9
SQ	2253	478	2389	511	6.7	2310	463	2408	536	4.4
LP	2191	498	2250	473	3.1	2230	479	2319	521	4.5

$\bar{x}$ = mean values; SD = standard deviations; MIF-L = maximum isometric force of the left leg; MIF-R = maximum isometric force of the right leg; % = percent; T1 = pretest; T2 = post-test; N = newtons; CON = control group; SQ = squat group; LP = leg press group

Table 3

Means, standard deviations and changes in the rate of force development (N/ms) from pre- to post-testing

	RFD-L					RFD-R				
	T1		T2			T1		T2		
	$\bar{x}$	SD	$\bar{x}$	SD	%	$\bar{x}$	SD	$\bar{x}$	SD	%
CON	11.2	3.0	10.2	2.9	-7.9*	11.5	2.5	10.8	2.7	-6.2*
SQ	12.6	2.6	12.4	3.1	-0.4	13.3	2.6	12.4	2.3	-5.8*
LP	11.2	2.3	11.1	2.6	0.3	11.5	2.6	11.2	2.6	-2.3

*$\bar{x}$ = mean values; SD = standard deviations; RFD-L = rate of force development of the left leg; RFD-R = rate of force development of the right leg; % = percent; T1 = pretest; T2 = posttest; N = newtons; * = significantly ($p<0.05$) different from the pretest within a group; CON = control group; SQ = squat group; LP = leg press group*

Table 4

Means, standard deviations and changes in the SJ and CMJ

	SJ					CMJ				
	T1		T2			T1		T2		
	$\bar{x}$	SD	$\bar{x}$	SD	%	$\bar{x}$	SD	$\bar{x}$	SD	%
CON	33.2	6.7	33.4	6.7	-0.01	37.1	7.5	35.9	7.5	-3.9*
SQ	33.6	5.3	38.2	5.3	14.2*	36.7	6.0	41.4	6.2	13.4*
LP	32.3	6.4	33.9	6.7	5.2	36.0	7.4	37.0	7.6	3.3

*$\bar{x}$ = mean values; SD = standard deviations; SJ = squat jump; CMJ = countermovement jump; % = percent; T1 = pretest; T2 = post-test; * = significantly (p<0.05) different from pretest within a group; CON = control group; SQ = squat group; LP = leg press group*

Table 5

Means, standard deviations and changes in dynamic maximum strength (squat/leg press; [kg]) and maximum isometric strength (sum of the 2 values from the unilateral testing [N])

	1RM					MIF-LR				
	T1		T2			T1		T2		
	$\bar{x}$	SD	$\bar{x}$	SD	%	$\bar{x}$	SD	$\bar{x}$	SD	%
CON	75.6	23.9	75.9	21.0	1.7	4236	1003	3984	905	-5.2
	220.7	88.1	226.9	64.7	7.7					
SQ	97.1	29.0	118.0	29.4	23.9*	4563	904	4797	1010	5.4
LP	230.3	57.4	296.8	68.3	30.5*	4435	933	4576	959	3.7

*$\bar{x}$ = mean values; SD = standard deviations; SJ = squat jump; CMJ = countermovement jump; % = percent; T1 = pretest; T2 = post-test; * = significantly (p<0.05) different from the pretest within a group; CON = control group; SQ = squat group; LP = leg press group; 1RM = one-repetition maximum; MIF-LR = maximum isometric force of the left and right leg.*

Table 6

Correlations of strength and speed-strength variables in the SQ group (n = 43)

	MIF-R	RFD-L	RFD-R	SJ	CMJ	MIF-LR	1RM
MIF-L	0.86*	0.51*	0.47*	0.45*	0.40*	0.96*	0.70*
MIF-R	1	0.46*	0.57*	0.51*	0.48*	0.97*	0.69*
RFD-L		1	0.70*	0.20	0.22	0.50*	0.54*
RFD-R			1	0.46*	0.50*	0.54*	0.52*
SJ				1	0.96*	0.50*	0.72*
CMJ					1	0.50*	0.64*
MIF-LR						1	0.72*

*MIF-L = maximum isometric force of the left leg; MIF-R = maximum isometric force of the right leg; MIF-LR = maximum isometric force of the left and right leg; RFD-L = rate of force development of the left leg; RFD-R = rate of force development of the right leg; SJ = squat jump; CMJ = countermovement jump; * = significant (p<0.05)*

Table 7

Correlations of strength and speed-strength variables of the LP group (n = 40)

	MIF-R	RFD-L	RFD-R	SJ	CMJ	MIF-LR	1RM
MIF-L	0.85*	0.60*	0.58*	0.48*	0.49*	0.96*	0.54*
MIF-R	1	0.68*	0.76*	0.56*	0.57*	0.97*	0.67*
RFD-L		1	0.87*	0.51*	0.53*	0.67*	0.54*
RFD-R			1	0.56*	0.56*	0.70*	0.57*
SJ				1	0.97*	0.56*	0.66*
CMJ					1	0.57*	0.68*
MIF-LR						1	0.64*

MIF-L = maximum isometric force of left leg; MIF-R = maximum isometric force of right leg;
MIF-LR = maximum isometric force of left and right leg;
RFD-L = rate of force development of left leg; RFD-R = rate of force development of right leg;
*SJ = squat jump; CMJ = countermovement jump; * = significant (p<0.05)*

Discussion

The main findings of this study include: first, the comparison of the squat and the leg press shows the squat to be a more effective exercise for increasing jump performance in short-term strength training; second, collecting strength/force data, the procedure should be carefully considered based on the desired test variables.

Statistically significant changes ($p \leq 0.05$) in maximum dynamic strength were found for both training groups, but the isometric maximum force did not improve significantly. This observation may be explained in two different ways: numerous investigations have shown that increases in performance tests are greatest if training was performed in the same contraction type that is performance limiting (Farting and Chillibeck, 2003; Paddon-Jones et al., 2001). This is due to divergent innervation strategies used by the central nervous system (CNS; Kinugasa et al., 2005; Komi et al., 2000). For both training groups concentric phases of the exercises were performance-limiting. Since most of the increases in maximum strength observed are likely to be primarily due to neural adaptations (Aargaard et al., 2002; Moritani and DeVries, 1979), it is further likely that the enhanced activation of the lower extremities could not be retrieved in the isometric testing conditions.

The measurement of the 1RM was performed bilateral compared to unilateral measurements of the isometric force production. As studies on the bilateral deficit show (Häkkinen et al., 1996; Howard and Enoka, 1991), the rate of performance change is influenced by the test conditions. However, the accumulated benefits of unilateral tests are higher than for bilateral tests. Therefore, the MIF LR should have shown an especially good performance increase, but this was not the case. Another difficulty arises from the fact that an isometric measurement has to be angle specific by definition. As maximum isometric force was determined at the 120° knee joint angle (for previously described reasons), the highest activity of the central nervous system is found at about 60-70° in the squat and at 90° in the leg-press. Thus, it can be assumed that the angle-specific adjustments played an important role in our observations (Knapik et al., 1983). This demonstrates a problem in diagnostic practice as data of strength variables are often assessed in isometric conditions. Especially in short-term studies of only a couple of weeks intervention period, one could assume isometric maximum testing not to be sensitive enough to reveal increases in strength performance through dynamic exercises.

Considering the results of the collected speed-strength variables, a similar problem might occur. None of the groups showed statistically significant improvements in the RFD. On the contrary, the LP group even presented a significantly decreased RFD of the right leg. Based on the improvements of the other variables in this group it cannot be attributed to fatigue effects. Whether subjects were less motivated performing the isometric tests compared to dynamic measurements cannot be answered. Furthermore, no significant changes in the SJ were observed, whereas a significant decrease in the CMJ performance occurred. Given that both variables were highly correlated ($r = 0.97$, $p \leq 0.01$), this is surprising, especially since the CMJ is not such a complex motor task that its execution might have negatively affected the results.

However, even more surprising are the differences found in the development of jump performance of both training groups. The SQ group presented highly significant increases in the SJ (14.2%) and CMJ (13.4%), whereas no statistically significant changes were found for the LP group (SJ increased by 5.2% and CMJ by 3.3%). As the differences between both training groups were also statistically significant, it can be concluded that training using the barbell squat is superior to the leg-press (concerning increases in jump performance). Probably, the greater benefit of the barbell squat is that the body position corresponds better with the tested jumps. The similarities of the squat and the SJ / CMJ are likely to facilitate the transfer of performance increases. Therefore, it seems to be easier for the CNS to transfer a high level of activation between these three motor tasks compared to the leg-press. Aside from this, it was still surprising that changes of the LP group did not reach significance as the maximum dynamic strength gains were high. Therefore, it was expected to find at least some transfer of the enhanced ability to activate the muscles in the SJ and CMJ.

In the first step, the analysis of correlations was performed separately for both training groups. That is why we were able to determine if the correlations between maximum strength and the other variables were influenced by the choice of strength training exercise. In the second step, the correlations were calculated for the entire sample. The relationship between maximum dynamic strength and isometric force (MIF LR) for the entire sample was $r = 0.64$ ($p \leq 0.01$) and therefore, similar to the correlation between the maximal leg-press performance and isometric measures. The SQ group alone had $r = 0.72$ ($p \leq 0.01$) and the combination of SQ and Con groups showed $r = 76$ ($p \leq 0.01$). The correlations for the two maximal strength measures were between $r = 0.64$ to $r = 0.76$ for the different sample groups and thus, remarkably low. For comparison, Schmidtbleicher (2003) reported correlation coefficients of $r > 0.85$ up to $r > 0.90$ for athletes. Once again, different hip and knee angles, contraction types and uni- vs. bilateral testing seem to exhibit a great influence on the results and therefore, suppress the expected high correlation coefficients. We found even lower correlation coefficients between the RFD and 1RM (range from $r = 0.52$ to $r = 0.61$; $p \leq 0.01$) and correlation coefficients between 0.51 and 0.76 ($p \leq 0.01$) for the comparison of the RFD with the isometric measures. Correlation coefficients around $r = 0.70$ for the relationship between maximal strength and the RFD confirm the basic assumption that speed-strength is highly dependent of the maximum force production capacity. The correlation coefficients for jump performance and the RFD are slightly lower as the aforementioned factors affect this relationship (between 0.46 and 0.56; $p \leq 0.01$). The values for the relationship between the RFD-L and SJ and CMJ for the LP group, $r = 0.20$ ($p > 0.05$) and $r = 0.22$ ($p > 0.05$), respectively, are difficult to explain.

The influence of maximum dynamic strength on jump performance should be considered as moderate to high ($r = 0.64$ to 0.79, $p \leq 0.01$), depending on the test conditions. This is in accordance with our expectations. The type of testing is therefore not important in maximum dynamic strength of the lower extremities. Correlations to maximum isometric measures are significantly lower (between $r = 0.40$ and $r = 0.57$; $p \leq 0.01$). Furthermore, changes in the contraction type, different joint angles and possibly uni- vs. bilateral testing perturb the correlations.

Practical Implications

Based on the present findings there are two implications for coaches and athletes: first, our data suggest a large influence of selection of the training exercise on short term performance improvement. The squat was shown to be significantly more effective compared to the leg-press. Therefore, in the pre-competitive period the barbell squat should be preferred, owing to better transfer effects on jump performance. Second, when collecting strength data, the procedure should be carefully considered. The data presented here indicate the problems arising when measurements based on motor tasks with dynamic execution (when the joint angle varies over the range of motion) are compared to values collected with other contraction types and at a specified joint angle (isometric measurement, often used in therapy and comprehensive sport).

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Corresponding author:

Michael Keiner
Swimming Federation of the State Lower Saxony, Hannover, Germany
Ferdinand-Wilhelm-Fricke-Weg 10
30169 Hannover
Phone: +491632784652
E-Mail: Michaelkeiner@gmx.de