EFFECTS OF DIFFERENT PERIODIZATION MODELS ON RATE OF FORCE DEVELOPMENT AND POWER ABILITY OF THE UPPER EXTREMITY

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ABSTRACT

Hartmann, H, Bob, A, Wirth, K, and Schmidtbleicher, D. Effects of different periodization models on rate of force development and power ability of the upper extremity. *J Strength Cond Res* 23(7): 1921–1932, 2009—The purpose of our study was to compare the effects of 2 different periodization models on strength and power variables under dynamic and static conditions in the bench press. Participants of the experimental groups were male sport students experienced in weight training (age: 23.98 ± 3.14 yr). Subjects were tested for the 1 repetition maximum (1RM) in the bench press, maximal movement velocity (Vmax) in the bench press throw (16.9 kg), maximal voluntary contraction (MVC), and maximal rate of force development (MRFD) in 90° elbow and shoulder angle in the isometric bench press. According to their 1RM, subjects were parallelized and assigned to 1 of either 2 training groups: strength-power periodization (SPP, $n = 13$) or daily undulating periodization (DUP, $n = 14$). Subjects trained for 14 weeks, 3 days per week. In the strength-power sessions, both groups were instructed to lift the weight as explosively as possible. In addition, a control group ($n = 13$) was used for comparison. One repetition maximum and Vmax improved significantly through training ($p \leq 0.05$), with no significant changes in MVC and MRFD. Experimental groups showed no significant group differences in any variable. The results indicate that, in short-term training using previously trained subjects, no differences in 1RM and power are seen between DUP and SPP. As used in our undulating regime, additional training in strength endurance could lead to exhaustion effects and furthermore does not provide an adequate training stimulus for power because of its low training intensity. In spite of this, according to the present findings, it has no negative effect on the application of a neural stimulus that is needed for a strength-power session if adequate regeneration time between workouts is guaranteed.

KEY WORDS daily undulating, bench press, speed-strength

INTRODUCTION

An appropriate periodization of training is needed for achieving top results in high-performance sports. Influenced by concepts originated in the former Eastern Bloc (21,29), Stone et al. (54) developed a periodization concept for strength and power sports named strength-power periodization (SPP), also known as linear periodization (6,9). The primary underlying concept of periodization in general, and of SPP in particular, is to transfer a variety of performance variables (power, strength, or local musculature endurance) to their highest rate of development with the aim of peaking at a precise time and avoiding any stagnation, injury, and overtraining (21,54). This is accomplished through variation in consecutive phases (mesocycles) within the preparation and competition period. Their according load dynamics follow the Soviet pattern: high initial training volume with low-intensity (hypertrophy phase), followed by an increased intensity with simultaneously decreased volume (strength and power phases) converging to an intensity peak (peaking phase). Whereas each training phase lasts for 2 to 6 weeks, the complete training cycle ranges over approximately 8 to 24 weeks (21). In the long term, the amount of muscle cross-sectional area (CSA) is believed to be the crucial factor for high maximum strength and power behavior (22,49,64). Therefore, the prime focus within the preparation period (general stage) is an increase of muscle mass to enhance the athlete's strength potential (49). The major goal of the following strength and power phases (special stage) is to improve the intramuscular coordination associated with the voluntary innervation of the newly gained contractile structures (49). Consistent findings of basic research provide support for the effectiveness of training with the method of "maximum explosive strength actions moving high weight-loads (>90%)" (50) for enhancing the rate of force development (RFD) (12–15,46,48,51) and the maximum strength and power ability (12–15,33,46,48,51,53) of the available muscle CSA.

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For the upper extremity, this method showed significant superiority over the "power method" with loads of 30% and 45% maximal voluntary contraction (MVC) (12,14,15,48,51,53). However, for well-trained athletes, the combined, gradual use of both methods, in addition to skill training, appears to provide an optimal development of strength and power behavior (56,60,65,66). The ability to produce a preferable steep RFD is identical for all load areas between 25% and 100% MVC (34) and is called maximal RFD (MRFD) (49). Ballistic movements against weight loads below 25% of MVC are determined from the initial RFD (IRFD) (49). Both IRFD and MRFD are constituted as the determining unit for movements with a duration of 250 milliseconds or less (49). For movements with a duration of more than 250 milliseconds, the maximum strength predominates (49). The augmentation of RFD especially depends on the maximum effort of producing a maximal muscle contraction speed regardless of actual movement velocity (7,12–15,18,34,35,46,48–51,65,66). According to Wirth and Schmidtbleicher (65), the muscle contraction speed is defined as the time a muscle requires to develop a specific tension value. Therefore, the effectiveness of a training stimulus depends on realizing a maximal and explosive ballistic impulse by proper activation of the neuromuscular system (7,12–15,18,34,35,46,48–51,65,66). "The term 'ballistic' implies short starting time, maximum speed and no possibility of correcting or adjusting the movement during execution" (60). According to the last criterion, explosive ballistic actions are therefore "preprogrammed" (Keele 1968, cited in 18). The resulting command from the central nervous system for the ballistic innervation pattern effects a temporal compression of the recruitment domain of the motor units, with a modulation of highest innervation frequencies over 100 Hz for fastest RFD (13,18). This explains the positive training effect of maximum explosive strength actions (>90% 1RM) on the power ability in the same movement (13,49,50,66).

Most of the studies comparing periodized strength training programs with subjects of low to high performance levels support the superiority of SPP in enhancing muscular strength and motor performance over nonperiodized single-set programs (28,57) and nonperiodized traditional programs (e.g., 3 × 6RM) (37,54,55,57,63), although contradictory findings exist (6,25). In Poliquin's (39) belief, however, this progressive process of intensity of SPP in well-trained athletes may increase the likelihood of stagnation in the training progress and warrants no more appropriate stimulus for morphologic adaptations. For this reason, Poliquin recommends more variable load dynamics by rotating hypertrophy- and strength-power phases each with 2 weeks of duration and increasing intensity. His model is called "undulating periodization" (UP) (21), also referred to nonlinear periodization (9,28,29). Baker et al. (6) found significant improvements in vertical jump height (jump and reach test) ($p \leq 0.05$) and dynamic maximum strength for the squat and bench press ($p \leq 0.05$) elicited through SPP ($n = 8$), UP ($n = 5$), and a nonperiodized control method ($n = 9$). The training period lasted 12 weeks (3 days/wk) and was performed with previously trained subjects. There were no statistically significant group differences for any performance variable after training. Buford et al. (11) confirmed these findings for SPP and weekly UP after a 9-week training protocol for dynamic maximum strength gains in bench press and leg press exercises with recreationally trained subjects. A superiority of UP in increasing dynamic maximum strength is only documented in comparison with nonperiodized traditional programs in bench press and squats with Russian athletic throwers (Ivanov, Krugliy and Zinchenko 1980, cited in 41) and after 12 weeks of squat training with previously trained subjects (55).

Kraemer (28) examined a more frequent change of training methods within the same week, which is known as "daily undulating periodization" (DUP) (21). The periodized strength training program, performed for 24 weeks 3 days per week with Division III football players ($n = 22$), resulted in significant increases ($p \leq 0.05$) in dynamic maximum strength in bench press and leg press as well as countermovement-jump height. The training protocol comprised additional special strength training exercises (hang cleans, power cleans), and thus it is not comparable with the effects of general strength training on power alone. The training results were compared with those of a single-set group ($n = 22$) and showed significant group differences ($p \leq 0.05$) for DUP.

Petersen et al. (38) alternated general (squat, bench press), special (e.g., barbell-loaded squat jumps), and specific strength training (various jump exercises, sprints of various distances) in a daily undulating profile ($n = 7$) and compared the effects with a successive application of these exercises in an SPP model ($n = 7$) with firefighters over a 9-week strength training course (3 times/wk). The first 2 mesocycles included general strength training (squat, bench press), and the last was executed with special and specific exercises. Performance variables (1 repetition maximum [1RM] bench press, 1RM squat, peak power output at 60% 1RM barbell back squat) significantly ($p \leq 0.05$) increased for both groups with a trend in favor of DUP. However, applying special and specific training exercises in a periodization model allowed no dissociation between different training stimuli and their influences on power gains.

According to our knowledge, there are no more than 2 training studies comparing SPP and DUP models that included only general strength training exercises. Rhea and colleagues (41) found significant increases ($p \leq 0.05$) in dynamic maximum strength in leg press and bench press for both periodization models (SPP, $n = 10$; DUP, $n = 10$) after 12 weeks of training (3 workouts/wk). Subjects were recreationally trained men. In comparing group differences, DUP induced greater percentages of dynamic maximum

TABLE 1. Subject characteristics at baseline: group mean ± *SD*.

Group	*n*	Age (yr)	Body height (cm)	Body weight (kg)
SPP	13	24.31 ± 3.17	183.85 ± 7.18	84.72 ± 11.20
DUP	14	25.14 ± 3.98	177.57 ± 7.49	79.44 ± 10.38
C	13	24.77 ± 3.09	180.53 ± 8.06	74.42 ± 12.06

*SPP = strength-power periodization group; DUP = daily undulating periodization group; C = control group.

strength gains ($p \leq 0.05$) in both performance tests. However, analysis of absolute strength increases demonstrated significant group differences ($p \leq 0.05$) only for the leg press but not for the bench press. Buford et al. (11) compared 3 periodization models (SPP, $n = 9$; DUP, $n = 10$; weekly UP, $n = 9$) over a 9-week training course with recreationally trained subjects (3 workouts/wk). Dynamic maximum strength in bench press and leg press significantly ($p \leq 0.05$) increased for all 3 groups, but no statistically significant group differences were seen.

The current available data permit no distinct conclusion about the superiority of a DUP over an SPP model in enhancing the dynamic maximum strength behavior. A high maximum strength level can be regarded as the basic determinant for power (12–15,26,33,34,46,48,49,56,65). The purpose of our study was to compare the effects of different periodization models (SPP and DUP) on the maximum strength ability. Their specific influence by means of a general strength training on power production and isometric force generation may offer meaningful conclusions about their effectiveness for power sports.

METHODS

Experimental Approach to the Problem

The objective of this study was to compare the effects of the DUP and SPP on muscular strength and power in the bench press with subjects predominantly experienced in strength training. The SPP model is used to enhance morphologic adaptations (hypertrophy phase) and neural adaptations (strength and power phases) in consecutive phases (21). However, the DUP protocol features strength-power days, bodybuilding hypertrophy days, and strength endurance days in a rotational manner to develop collectively strength, power, local musculature endurance, and tissue hypertrophy (28). The following parameters were assigned as dependent variables: maximal movement velocity (Vmax) in the bench press throw, MVC, and MRFD in the isometric bench press and 1RM in the bench press. The method of periodization (SPP and DUP) was designated as the independent variable.

Subjects

Forty male sport students volunteered for this study and were recruited from the Institute of Sport Sciences, Goethe University, Frankfurt/Main, (Table 1). Each subject was informed of the experimental risks of the research and signed an informed consent document before the investigation. The research design was approved by an institutional review board for use of human subjects. The investigation was conducted during the summer term of 2004. Prerequisite for participation in the experimental groups was strength training experience in the bench press with a minimum 1RM of 100 kg. Because of a lack of strong sport students, we resorted to enlisting weaker subjects as well (1RM pretest: min. 60 kg; max. 135 kg). The experimental groups constituted the following relative strength of 1RM in the pretests: SPP 1.15 (±0.25) kg/kg bodyweight, DUP 1.21 (±0.15) kg/kg bodyweight.

Procedures

According to their 1RM, subjects were parallelized and assigned to 1 of either 2 training groups: SPP ($n = 13$) or DUP

TABLE 2. Load dynamics of experimental groups during entire 14 weeks of periodized strength training program.

Group		Load dynamics		Rest of set (min)
Strength-power periodization (*n* = 13)	Week 1–10:	Hypertrophy phase	5 × 8–12RM	4
	Week 11–14:	Strength-power phase	5 × 3–5RM	5
Daily undulating periodization (*n* = 14)	Week 1–14			
	Monday:	Strength-power training	5 × 3–5RM	5
	Wednesday:	Hypertrophy training	5 × 8–12 RM	4
	Friday:	Strength endurance training	5 × 20–25RM	1.5

*RM = repetition maximum.

($n = 14$) whereby homogeneity of groups was warranted at baseline. In addition, a control group of sport students ($n = 13$) were enrolled for comparison. Subjects of both experimental groups performed the bench press exercise 3 days per week for 14 weeks. The SPP program was separated into 2 blocks. Block 1 comprised a hypertrophy phase of 10 weeks, which was meant to increase the muscle mass and thereby enhance strength potential (49). Block 2 included a strength-power phase of 4 weeks with the method of "maximum explosive strength actions moving high weight-loads (>90%)" (50) to improve intramuscular coordination, which is associated with the voluntary innervation of the newly gained contractile structures (49).

The DUP group trained with the undulating schedule with a daily load dynamic over the entire 14 weeks of the study (Table 2). We chose great differences in the repetition scheme of each training zone to induce distinct adaptations for the particular training phases. In the strength-power sessions, both groups were instructed to lift the weight with maximum explosive effort (49,66). Bouncing the bar on the chest in the eccentric-concentric transition phase was not allowed in any training session. Subjects performed each set to momentary muscular failure in the last 2 repetitions of the targeted repetitions scheme (forced repetitions). The investigators provided spotting and strong verbal encouragement. If necessary, the resistance was adapted to 2.5 to 10 kg for the next set or next training session so that the subject was able to perform the particular repetition scheme. Subjects were permitted to continue their common strength training programs with the exception of no exercises for M. pectoralis major, M. deltoideus pars clavicularis, and M. triceps brachii. Subject exclusion criterion was missing more than 3 of the training sessions.

Testing

Pretests were carried out 5 and 3 days before the first training session. Pretest 1 was a familiarization session for Vmax in the bench press throw and 1RM in the bench press. In addition to Vmax and 1RM, pretest 2 made measurements of MVC and MRFD in the isometric bench press. The test procedures took place in the following order: measurement of Vmax in the bench press throw, MVC and MRFD in the isometric bench press, 1RM in the bench press. The best trials of both pretests are illustrated in Table 3. Detraining tests were performed 7 and 14 days after the last training session. Both post-tests included the same test procedures as pretest 2. The best trials of both post-tests are illustrated in Table 3.

Bench Press Throw. The bench press throw involved a concentric action at a constant weight of 16.9 kg. The test was performed using a Smith machine. The subjects lay on a bench, which was modified in height so that the bar was just above the chest (Figure 1). Subjects' hands had to be placed on fixed markings of the bar. The subjects were instructed to apply force as quickly as possible and throw the bar for maximal height by releasing it (Figure 2). With this measuring system, it is possible to calculate the Vmax in the bench press throw (46). The subjects performed as many trials as they were able, to better their best trials or to confirm

Table 3. Mean values and *SD*s of different training variables of all groups before and after 14-week periodized strength training program.

		Pretraining	Posttraining	Change (%)
Variable	Group	Mean ± *SD*	Mean ± *SD*	Mean ± SD
1RM (kg)	SPP	96.54 ± 20.91	109.42 ± 19.64†	14.63 ± 11.02†‡
	DUP	95.89 ± 17.45	105.36 ± 19.46†	9.96 ± 4.52†‡
	C	58.46 ± 10.23	59.23 ± 10.48	1.38 ± 5.84
MVC (N)	SPP	880 ± 178	914 ± 223	3.82 ± 11.91
	DUP	947 ± 199	940 ± 226	−0.86 ± 9.56
	C	609 ± 142	592 ± 151	−2.46 ± 11.29
MRFD (N/ms)	SPP	9.92 ± 2.17	10.1 ± 2.38	7.06 ± 36.46
	DUP	10.79 ± 1.99	10.78 ± 2.12	1.61 ± 21.71
	C	7.72 ± 2.39	7.31 ± 2.26	−2.5 ± 23.96
Vmax (m/s)	SPP	3.03 ± 0.31	3.25 ± 0.28†	7.61 ± 4.29†‡
	DUP	2.99 ± 0.27	3.17 ± 0.31†	6.14 ± 4.82†‡
	C	2.67 ± 0.23	2.7 ± 0.24	1.17 ± 3.9

*1RM = 1 repetition maximum; MVC = maximal voluntary contraction; MRFD = maximal rate of force development; Vmax = maximal movement velocity against a constant weight of 16.9 kg; SPP = strength-power periodization group ($n = 13$); DUP = daily undulating periodization group ($n = 14$); C = control group ($n = 13$).

†Significant difference pre to post ($p \leq 0.05$).

‡Significant group difference to control group ($p \leq 0.05$).

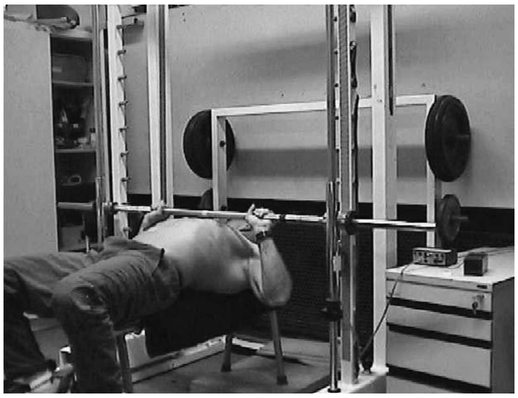

Figure 1. Bench press throw for measuring maximal movement velocity moving a constant weight load of 16.9 kg. Starting position of bench press throw.

these as their best. Test-retest reliability of both pretest sessions constituted $r = 0.94$ (Pearson; $p \leq 0.01$).

MVC and MRFD. MVC and MRFD were recorded in the isometric bench press. The subjects lay on a table with a 90° angle in the elbows and armpits. They were instructed to develop force as explosively as possible on command. The subjects performed as many trials as they were able, to better their best trials or to confirm these. The MRFD or "explosive strength" (12,15) is calculated as the maximal slope of the recorded force-time curve. Test-retest reliability could not be conducted because isometric measurements were performed only in the second pretest session. Using the same measuring system in our laboratory, Schlumberger (46) determined a test-retest reliability between $r = 0.92$ and $r = 0.97$ for MVC and $r = 0.72$ to $r = 0.84$ for MRFD in different test sessions.

Figure 2. Bench press throw for measuring maximal movement velocity moving a constant weight load of 16.9 kg. End of movement with releasing of bar.

Strength Testing. The bench press exercise was performed with a maximum weight so that the bar was lowered to touch the chest gently, at the level of the nipples, and pushed up to arms' length. Cheating by bouncing the bar on the chest in the eccentric-concentric transition phase was not allowed. Test-retest reliability of both pretest sessions constituted $r = 0.98$ (Pearson; $p \leq 0.01$).

Statistical Analyses

The best trials of 1RM, Vmax, MVC, and MRFD were recorded and analyzed. First, the Shapiro-Wilk normality test was used to quantify the deviation of the actual data and its Gaussian distribution. Homogeneity of variance was proven with the Levene test. Test requirements were fulfilled at a significance level of $p \leq 0.05$. Pretraining values of both experimental groups were tested for a significant difference using a one-way analysis of variance (ANOVA) ($p \leq 0.05$). In addition, a Pearsońs product moment correlation test was performed to examine the relationship between variables. Comparison of group and test times of the dependent variables from both experimental groups was made by way of a two-way ANOVA for assessing main effects and interactions. If significant effects for the factor test time or interaction occurred, the Scheffé test was applied post hoc ($p \leq 0.05$).

RESULTS

Results for all variables of the 3 groups for the pre- and posttests are shown in Table 3 and Figure 3. Measurement of body weight showed no statistically significant differences from baseline to post-training for the 3 groups.

Dynamic Maximum Strength

The SPP and DUP groups both significantly increased their performances in the 1RM bench press by 14.63 ± 11.02% ($p \leq 0.05$) and 9.96 ± 4.52% ($p \leq 0.05$), with no statistically significant difference between the groups. Both experimental groups showed a significant difference with the control group ($p \leq 0.05$), which achieved no significant change of 1.38 ± 5.84%.

TABLE 4. Correlations between different test variables in post-tests of both experimental groups.

Variable	MVC	MRFD	1RM
MRFD	0.33	–	–
1RM	0.71‡	0.30	–
Vmax	0.43†	0.13	0.79‡

*1RM = 1 repetition maximum; MRFD = maximal rate of force development; MVC = maximal voluntary contraction; Vmax = maximal movement velocity.

†Significant correlation ($p \leq 0.05$).

‡Very significant correlation ($p \leq 0.01$).

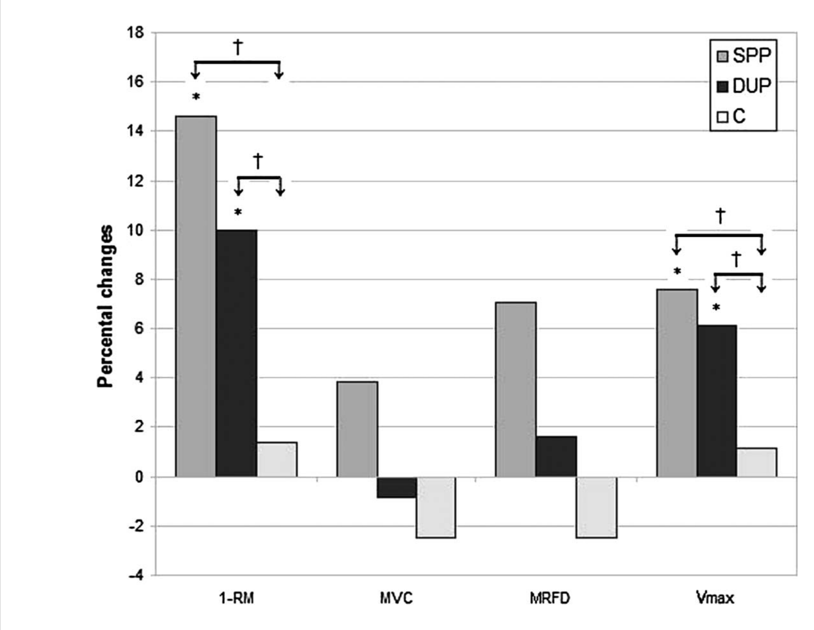

Figure 3. 1-RM = one-repetition maximum; MVC = maximal voluntary contraction; MRFD = maximal rate of force development; Vmax = maximal movement velocity against a constant weight of 16,9 kg; SPP = strength-power periodization group (*n* = 13); DUP = daily undulating periodization group (*n* = 14); C = control group (*n* = 13); * = significant difference pre to post ($p \leq 0{,}05$); † = significant group difference to control group ($p \leq 0{,}05$).

MVC

After training, no group showed statistically significant changes. The SPP and DUP groups showed changes of 3.82 ± 11.91% (ns) and –0.86 ± 9.56% (ns), with no significant difference between groups. Both experimental groups achieved no significant difference with the control group, which showed no significant change of –2.46 ± 11.29.

MRFD

After training, no group showed statistically significant changes. The SPP and DUP groups showed changes of 7.06 ± 36.46% (ns) and 1.61 ± 21.71% (ns), with no significant difference between groups. Both experimental groups showed no significant difference with the control group, which achieved no significant change of –2.5 ± 23.96%.

Bench Press Throw

The SPP and DUP groups both significantly increased Vmax in the bench press throw by moving a constant weight of 16.9 kg by 7.61 ± 4.29% ($p \leq 0.05$) and 6.14 ± 4.82% ($p \leq 0.05$), with no significant difference between groups. The experimental groups showed a significant difference with the control group ($p \leq 0.05$), which showed no significant change of 1.17 ± 3.9%. The weight of 16.9 kg, which was meant to be accelerated, represented between 11.46% and 24.14% of the individual dynamic maximum strength of both experimental groups in the post-tests.

DISCUSSION

Many training interventions with durations between 9 and 24 weeks, performed with subjects experienced in resistance training, have demonstrated the established positive effect of periodization on the development of the dynamic maximum strength ability. Both a SPP model (6,11,28,63) and a DUP model (11,28,41) with a similar training frequency of 3 days per week caused significant gains in the 1RM bench press. In the present study, most of the subjects were relatively experienced in the bench press (relative 1RM pretest: SPP 1.15 [±0.25] kg/kg bodyweight; DUP 1.21 [±0.15] kg/kg bodyweight), and thus it can be presumed that the intermuscular effects on the dynamic strength increases were minor. However, the significant speed-strength improvements of both groups imply a great potential of an enhanced intramuscular coordination: the weight of 16.9 kg, which was meant to be accelerated, represented between 11.46% and 24.14% of the individual dynamic maximum strength of both groups in the post-tests. Weights below 25% of MVC, according to the findings of Müller (34), require a maximal explosive action to give the bar its highest possible terminal velocity. The cited target value of 25% is relative to the absolute strength maximum. Indeed, the larger number of our subjects achieved permanent higher strength values under dynamic compared with isometric strength testing. Therefore, the dynamic maximum strength values must serve as the dependent criterion. It can be assumed that increases of MRFD (12–15,46,48,51) and, according to Schmidtbleicher (49), particularly for improvements in IRFD, are responsible for the present findings. Basic research (18,31,34) supports the necessity for realizing a maximal impulse under explosive ballistic action conditions to a) innervate as many motor units as possible within the shortest time as well as b) activate each individual motor unit with the highest innervation frequency. Apparently, both periodization models induced a faster motor unit recruitment (8,18,31,51) and increased innervation frequencies of the α-motoneurones (13,18,31) at the onset of contraction. Furthermore, a stronger "input synchronization" (Freund 1983, cited in 19) with a more synchronized discharge behaviour of motor unit groups (19,31) could be another contributing main factor. These neuronal mechanisms stand in for an enhanced efferent neural drive, which could be verified as parallel increases of rate of rise in electromyography (EMG) and force development (1,7,18,51). In addition, it is referred to enhanced reflex potentiation after 14 weeks of periodized strength training caused by reduced presynaptic inhibition and/or enhanced excitability of the α-motoneurone pool (2).

The augmentation of RFD depends exceedingly on maximum effort to produce an explosive ballistic impulse, regardless of actual movement velocity (7,12–15,18,34,35,46,48–51,65,66). Bührle et al. (12–15), Schmidtbleicher (48,51), and Schlumberger (46) analyzed the effects of the method of "maximum explosive strength actions moving high weight-loads (>90%)" by using the bench press over 4 to 12 weeks with sport students. Their basic research showed maximum increases of MRFD between 28.7% and 55.5% in the isometric bench press along with significant ($p \leq 0.05$-0.01) improvements in speed-strength performance in the bench press throw. Moreover, Schmidtbleicher (48) found significant ($p \leq 0.05$) increases of IRFD (0 to 1/6 MVC) after an 8-week training block executed with 20 sport students (1). These results imply a more effective exploitation of the existing muscle potential (49). Moving high-weight loads (>90%) with maximum explosive effort guarantees the rapid recruitment of all muscles fibers that can be voluntarily activated (49,60), involving contractions long enough "to develop a complete mechanical efficiency for the most phasic motor units" (51). This compels the motor neurons to fire high-frequency impulses for proportionally long times (60). The rise time of onset of activation until achievement of the maximal innervation level of the complete α-motoneurone pool accounts for approximately 60 to 80 milliseconds in untrained persons (13), whereby the muscle is fully activated for the maximal voluntary innervation level even for short-term ballistic contractions of 100 to 150 milliseconds in duration while moving minimal weight loads (34,35). Strength-power training with this method can considerably reduce this period of motor unit activation, in individual cases to 25 to 30 milliseconds (51). Because the RFD is determined through this temporal compression of the recruitment sequence (13,18,34,35,51), this explains the positive training effect of maximum explosive strength actions on the speed-strength performance in our study. Furthermore, Schmidtbleicher and Haralambie (53) observed a significant ($p \leq 0.01$) shortening of contraction time of M. deltoideus pars clavicularis and M. triceps brachii caput longum (time to peak of contraction with threshold stimuli) after 8 weeks of maximum explosive strength actions in the bench press (4 workouts/wk).

Although IRFD (<50 ms) is moderately related to intrinsic muscle contractile properties and maximum muscle strength (4), maximal RFD (150–250 ms) depends mainly on the maximum strength ability (4) associated with the available muscle CSA (12,23,43). In the literature, correlations are found between RFD and maximum strength in subjects of different performance levels from $r = 0.40$ to $r = 0.89$, and this means that RFD can be influenced by over 40% through the maximum strength ability (4,12,26,30,34,36). The present findings confirm the established belief that training with the method of "maximum explosive strength actions moving high weight-loads (>90%)" enhances the power and dynamic maximum strength ability of the available muscle fiber CSA.

The primary goal of general strength training in power events constitutes an enhancement of single muscle action (46,49), whereby an appropriate intensity stimulus must be achieved (49,50,65). In DVP, additional training of strength endurance could intensity the exhaustion effects to those of the hypertrophy training session. Furthermore, it provides no adequate training stimulus because of its low training intensity. However, according to our findings, DUP produces no negative effect on the neural stimulus application. This is contradictory with reports of longitudinal studies by which resistance hypertrophy training between 4 and 12 weeks of duration caused low or negative effects on MRFD (13,27,47) and speed of motorunit activation (51), although conflicting findings for strength training novices exist (67). Furthermore, Verkhoshansky (1979, 1981, cited in 56) reported a diminished power-capability among track and field athletes, which could occur after several weeks of concentrated load of strength or strength-endurance training. Repetitive submaximal dynamic contractions (hypertrophy, strength endurance training) are influenced by strong peripheral fatigue because of the accumulation of high metabolic byproducts (H^+-ions, adenosine diphosphate, anorganic phosphate) in the sarcoplasma and movements of electrolytes (Na^+, K^+) in the sarcolemma (44,58). Training-related high-serum lactate levels between 13 and 20 mmol/L (3,58) indicate a metabolic acidosis (42), which may exhibit a distinct depression of myofibrillar Ca^{2+} sensitivity (20) and interferences of Ca^{2+} kinetics. A decreased Ca^{+2} ATPase activity associated with depressed Ca^{+2}- reuptake by the sarcoplasmatic reticulum (SR) may cause a slowing in relaxation rate (44). Slowed reuptake of elevated cytosolic Ca^{+2} concentrations may therefore reduce SR Ca^{2+} release (44). These processes interfere with the electromechanical coupling (44) associated with the maximum muscle contraction speed through impaired cross-bridge cycling (20,44). Peripheral fatigue induces a decreased excitability of the α-motoneurone pool as well (12). However, enhanced firing rates (> 60–100 Hz) are an important adaptation process for developing a ballistic innervation pattern (13,18,31,34,45,51) and can hardly be maintained for 20 to 30 seconds by the highest-threshold motor units (Bigland-Ritchie et al., 1978, Dietz, 1978, Jones, Bigland-Ritchie and Edwards, 1979, Petrofsky and Lind, 1980, Viitasalo and Komi, 1978, cited in 12). Because the realization of a fast contraction depends also on the activation ability of the contractile system, peripheral fatigue may impair the capability of explosive actions (20).

It is to be expected that, in addition to the hypertrophy session, because of incomplete regeneration, strength endurance training most likely contributed to stimulus transmission failure through mechanical-induced damages of structural components (e.g., t-tubuli, SR). This may impair neuromuscular performance over several days (52,61). Ahtiainen and colleagues (3) still identified significantly ($p \leq 0.001$) decreased MVC values in bilateral leg extensions 48 hours after 2 different exhaustive bouts of hypertrophy training (serum lactate level 12.8 ± 3.1 mmol/L) with different rest periods between sets. Training sessions for both groups were carried out in leg presses (Group I: 5 × 10 RM, 2 min rest; Group II: 4 × 10 RM, 5 min rest) and squats (Group I: 4 × 10 RM, 2 min rest; Group II: 3 × 10 RM, 5 min rest) performed by recreationally strength trained men (Group I, $n = 5$; Group II, $n = 8$). However, 33 hours after a high-load strength training protocol in squats (3 × 3RM, 6 min rest), front squats (3 × 3RM, 6 min rest), and bilateral leg extensions (3 × 6RM, 4 min rest), Raastad and Hallén (40) already determined recovered isokinetic knee extension strength and squat jump height to baseline levels in 10 male athletes. According to the findings of Schmidtbleicher and Frick (52), after a bout of hypertrophy (80% 1RM, 5 × 8RM, 3 min rest) as well as strength endurance training (60% 1RM, 5 × 25RM, 1.5 min rest) in leg press, the recovery of power in the short stretch-shortening cycle (SSC; drop jumps) to baseline level is not expected until 72 hours compared with 3 hours after maximum explosive strength actions moving high-weight loads (90% 1RM, 5 × 3RM, 6 min rest). Subjects were sport students with strength training background ($n = 8$). Furthermore, power production in the short SSC showed potentiation effects 48 to 148 hours after the single strength-power training session (52).

To guarantee a maximum accentuation of the initial activation pattern in the strength-power training session, a training stimulus for neural applications demands maximum intensities in a completely rested state (49,50). For Kraemer and Fleck (29), the genius in undulating periodization is that lighter intensity training sessions (e.g., 12–15RM), or 50–60% 1RM, as used in our strength endurance training, allow rest of high threshold type II motor units that are used in the higher-intensity workouts. Subsequently, this provides for their recovery. In our opinion, this is very doubtful because scientific facts argue against "the idea of exclusive fiber type recruitment" (9). From intramuscular EMG studies, it is known that the maximal recruitment domain differs between muscles of different sizes because of different fiber type composition (31). Motor unit recruitment appears to be essentially terminated at approximately 50% MVC in small muscles (e.g., M. adductor pollicis) with mainly type I fibers and continues until 80–90% MVC in larger ones (e.g., M. biceps brachii, brachialis, deltoid muscles) composed of both type I and II fibers (31,45). "Small muscles may therefore be at increased risk for overtraining despite the implementation of light workouts because many FT fibers are recruited even with light resistance" (9). These data were collected with a small number of MVCs. As proven by glycogen utilization studies (5,58) and data from a longitudinal study (16) with muscle biopsies from M. vastus lateralis, it can be expected that high threshold type II units of large muscle groups are recruited during submaximal intensities as well. This muscle is composed of a mixed fiber type composition of type I and II fibers (16,43). It has been reported by Asp et al. (5) that the muscle glycogen concentration in type I and even in type IIa fibers are still depleted 2 days after a competitive marathon run in the M. vastus lateralis of well-trained male runners ($n = 6$). In addition to glycogen-depleted type I fibers, Tesch and colleagues (1998, cited in 58) also found depleted type IIa fibers in the M. vastus lateralis after 5 sets of 10 knee extensions at 30% and 45% 1RM. "At 60% 1-RM there was greater depletion and glycogen levels dropped in type IIb and IIab fibres as well…. This would infer these fibres are involved at loads lower than what is generally believed" (58). Because the load magnitude of the Tesch study was predominantly nonfatiguing, findings of strength training to muscular exhaustion with light loads demonstrates a more distinct comparison with our study. Campos and colleagues (16) detected conversions within the fast fiber population from type IIx to type IIa in the M. vastus lateralis after 8 weeks of strength endurance training with 3 leg exercises (leg press, squat, and leg extension, each with 2 × 20–28RM, 1 min rest) executed with untrained men ($n = 7$). This indicates a progressive recruitment of type IIx fibers into the contraction process as fatigue develops. All sets of our strength endurance training were performed to exhaustion following a similar repetition scheme (5 × 20–25RM, 60–50% 1RM, 1.5 min rest), which most likely resulted in the activation of the highest threshold motor units according to the aforementioned facts (16). The published findings of Schmidtbleicher and Frick (52) appear to be confirmed by the present results and may demonstrate a more plausible approach. The load dynamics of the DUP apparently supplied an adequate regeneration period of 72 hours between the strength endurance training session (Fridays) and the strength-power training session (Mondays) for assuring an optimally recovered neural stimulus transfer and transmission ability for maximal stimulus intensities (50). This could be an explanation for the significant increase of Vmax in the bench press throw for DUP. Our findings permit the conclusion of a possible combination between intensive training stimuli for neural adaptations with intensive lactic training stimuli for morphologic adaptations when these are applied in separate training sessions with an adequate regeneration time in between. On the other hand, if the neuromuscular system is challenged in parallel with competing training stimuli (neuronal vs. muscular) in the same training session, it is expected that a predominant constriction of the muscular component will occur (13,24).

Furthermore, both experimental groups showed a high correlation between dynamic maximum strength and Vmax in the bench press throw of $r = 0.79$ ($r \leq 0.01$). The post-test produced only low correlations between MRFD and MVC of $r = 0.33$ and between MRFD and 1RM of $r = 0.30$. Previous studies have established middle correlations in the bench press between MRFD and MVC between $r = 0.40$ and $r = 0.65$ (12) as well as between MRFD and 1RM of $r = 0.47$ (36). Indeed, the present study attests to a very significant and high correlation between MVC and 1RM ($r = 0.71$, $p \leq 0.01$) in the post-tests, as confirmed in the bench press of other studies (36: $r = 0.78$; $p \leq 0.01$; 12,50: $r = 0.95$). However, no significant change of MVC over the entire course of training was demonstrated. This could be because of the observed problem of muscle action specificity (45).

As during the early state of strength training when neural adaptations dominate, morphologic adaptations during later stages gradually become the primary factor in strength increases (32,45). The period in which appreciable morphologic changes occur (increase in muscle fiber CSA, transformation of muscle fiber types associated with myosin heavy chains, increase in the amount of connective tissue) and which may contribute to strength and power increases depends on the training status of the subjects, program variables (mainly volume and intensity), and the training exercise (multijoint or isolation exercise) (22,45). In multijoint exercises such as the bench press, the highest morphologic gains may be expected for muscle groups that showed the least pretraining condition (45). On the basis of the unfamiliar high-training frequency in this study, both groups may have shown significant gains in muscle CSA within the first 10 weeks (64), which may have contributed to the strength enhancements. Type II fibers are particularly considered to respond with a higher training-induced hypertrophy than type I fibers (22,58). Because of the greater proportional enhancements in their summed contraction force (P_0) associated with a higher hypertrophy-induced fiber peak power (62), these fibers may in particular cause an increase in RFD (23,34,59) and power (22,59) in the long term. A longitudinal study with strength training novices carried out with heavy loads (12 × 3–5RM, 3 min rest) (16) allow the belief that the strength-power phase could have caused significant hypertrophy effects as well. Schmidtbleicher and Bührle (51) conjectured for their own study that training with the method of "maximum explosive strength actions moving high weight loads (>90%)" over 12 weeks (4 times/wk) tended to result in increases in muscle CSA (3 × 3 × 90%, 2 × 2 × 95%, 1 × 1 × 100% and 1 × 1 × 100% MVC + 1kg, 5 min rest). For both training groups in the present study, it is possible that a change in the muscle fiber spectrum from type IIx to type IIa occurred as well. In accordance with Campos and colleagues (16), it is possible that correspondent transformations after 8 weeks of low- to high-intensity resistance training occurred (12 × 3–5RM, 3 min rest; 9 × 9–11RM, 2 min rest, or 6 × 20–28RM, 1 min rest).

After a bout of heavy-resistance exercise, the highest degree of adaptations of the contractile apparatus depend on the duration of the protein synthesis and the resynthesis of the contractile structure protein, respectively (22). The structural damages in the muscle determine the course of adaptations. The turnover of the contractile protein is probably approximately 7 to 15 days or even longer (22,61). The effects of a resistance training block are based on the additive virtues of single training sessions. The highest degree of training-induced speed-strength and explosive strength gains after completion of a training block probably depend on the time frame of the physiologic regeneration and adaptation processes (46). Schlumberger (46) investigated the effects of a 4-week strength training period in the bench press with the method of "maximum explosive strength actions moving high weight-loads" (>90%, 5 × 3RM, 6 min rest). Subjects were relatively experienced in strength training ($n = 10$) and trained 2 days per week. Schlumberger (46) identified a tendency ($p = 0.059$) of MRFD increases (28.7–14.6%) at least 3 to 10 days after the training block concomitant of significant gains ($p \leq 0.05$) in Vmax in the bench press throw in moving a weight load of 15.5 kg. The optimal development of Vmax in the bench press throw occurred with a time lag of 14 to 21 days of detraining. The weight with 15.5 kg, which was meant to be accelerated in the different test days, represented between 18.7% and 23.4% of the individual dynamic maximum strength (46).

In light of the significant gains in dynamic maximum strength and power in the present study, that the assumed neuronal adaptations showed no significant improvement of isometric MRFD after 7 and 14 days of detraining was very unexpected. According to Müller (34), the ability to produce a preferably steep RFD is identical for all load areas between 25% and 100% MVC. For ballistic movements below 25% MVC, this ability still shows a high correlation of $r = 0.76$ with the isometric MRFD (34). It has to be taken into account that the absence of significant enhancements of MRFD must also be related to the great intersubject variability of both groups (SPP min: −38.10%, max: 86.84%, DUP min: −14.29%, max: 51.52%). It is expected that for both groups an insufficient regeneration status as caused by stress-induced traumata is not responsible for the nonsignificant increase of MRFD after the 14-week training period. Nevertheless, many subjects complained about pain in their shoulders during the isometric post-tests. This could have been a negative influence on their performing a maximal impulse under isometric testing conditions. Maybe this explains the relatively low correlations between some isometric and dynamic measured parameters (Table 4). We missed the option of identifying the beginning of the isometric force-time curve in the first 30 (12) or 50 milliseconds (34). It is possible that this would have provided more clarification in regard to adaptations of the IRFD.

Practical Applications

For power sports, we can recommend UP with the present load dynamics because the present study showed equal results in the enhancement of dynamic strength and power for both periodization models. However, one must keep in mind that training interventions in general are insufficient or unable to simulate the stress situations and resultant exhaustion factors of competitive sports because of their comparatively short duration and lack of basic conditions (skill training, plyometric training). To provide better conclusions about the efficiency of DUP versus SPP in competitive sports, highly skilled athletes should undergo our load dynamic. It remains to be seen whether a single strength-power training session integrated in an undulating profile would be enough for highly skilled (power) athletes to produce equivalent effects as SPP on the measured parameters.

In the long term, the amount of muscle CSA is believed to be the deciding parameter for a high maximum strength and power behavior (22,49,64). Indeed, significant increases in muscle CSA of the upper extremity in untrained persons are already observable after 4 and up to 10 weeks after strength training (32,64), but longer durations of adaptation can be expected with subjects experienced in strength training. Brandenburg and Docherty (10) were unable to determine any significant increases in muscle CSA after 9 weeks of 2 different strength training programs (75–120% 1RM intensity). Hypertrophy training for the lower extremity, performed in multijoint exercises (squats, leg press), is partly expected to significantly increase muscle CSA after 20 to 24 weeks in trained (3) and untrained subjects (17). On the basis of these findings, Wirth (2004, p. 83) rightly posed the question of whether the lower extremity has to be confronted with a higher training volume to respond similarly with significant increases in muscle CSA over the same period. For this reason, the bigger part of the preseason periodization in individual sports should be oriented toward hypertrophy-orientated general strength training. We are not able to estimate the morphologic adaptations of DUP because these measurements were beyond the scope of our study and should be part of further investigations. A biweekly UP with rotating hypertrophy and strength and power phases (39) is not recommended because of underdosed stimulus frequency and inadequate workload. With subjects experienced in strength training, appropriate and significant morphologic adaptations require at least 2 hypertrophy-orientated strength training sessions per muscle and per week over a longer period (64). Instead, it is suggested that the load dynamic should rest on the reduction of volume with a concomitant increase of intensity during a macrocycle. To ensure the highest neuromuscular adaptation development by way of general strength training before a contest date, the peaking phase should normally be executed shortly before the contest (46,49). The correspondent aspects of skill training, which should match the coordinative aspects of contest movement, should be concomitantly increased (21,65). During the season, Fleck and Kraemer (21) suggest the use of UP with a daily load dynamic (4–6 reps, 8–10 reps, and 12–15 reps) for team sports, which should be suited to a high performance level over the entire course of the season. The authors assert that the disadvantages of SPP are low performance at the beginning of the season and the risk of over-fatigue at the end of the season. In our opinion, these effects depend rather on a general, inaccurate application of strength training rather than on the sort of periodization used. Hypertrophy-oriented strength training with program variables of 60–85% intensity 1RM (50) and multiple sets not exceeding 15 repetitions and at least 6 repetitions should serve as familiarization for team sport athletes unexperienced in strength training. Performing a large number of repetitions (>15) is unnecessary because it predominantly promotes local musculature endurance and therefore warrants no adequate training stimulus for gains in muscle CSA and strengthening (16).

Advancements of movement velocity in soccer, handball, tennis, and baseball may be expected in the execution of strength training in conjunction with technique training (DeProft et al. 1988, Dutta and Subramanium 2002, Hoff and Almåsbakk 1995, Lachowetz, Evon and Pastiglione 1998, Manolopoulos, Papadopoulos and Kellis 2005, Newton and McEvoy 1994, cited in 65). The facts support the high correlation between maximum strength and power ability (12–15,26,33,34,46,48,49,56,65, present results). During the season, it is possible to continue with hypertrophy strength training, but its use on those muscles relevant for the sport should be conducted at a distance of 3 to 4 days before a contest because of restricted neuromuscular performance through training-induced structural damage. Provided that the correct movement patterns of multijoint exercises (e.g., bench press, front squats, back squats) are established team sport athletes with a strength-training background should pay attention to higher training intensities (>90%). As determined by Schmidtbleicher and Frick (52), it is quite possible to perform a single training session with the method of “maximum explosive strength actions moving high weight-loads (> 90%)” at least 1 to 2 days before competition because of shorter regeneration times and potentiation effects (see Discussion) in power behavior after strength-power training. Thus, rotating hypertrophy- and strength-power sessions in a microcycle during the season is a viable option. Regarding neuromuscular performance, plyometric exercises can be executed after the strength-power training mentioned above if a minimum rest period of 3 hours is provided (46). For team sports, where strength training can only supply supplemental benefits, we recommend the gradual execution of higher loads with 3 to 5 repetitions in the first 2 to 3 sets of a training session to achieve an appropriate strengthening of the skeletal muscle during the limited time frame.

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