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Effect of Resistance-Training Programs Differing in Set Configuration on Maximal Strength and Explosive-Action Performance

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Purpose: To compare the effects of 2 upper-body strength-training programs differing in set configuration on bench press 1-repetition maximum (BP1RM), bench press throw peak velocity against 30 kg (BPT30), and handball throwing velocity. ***Methods:*** Thirty-five men were randomly assigned to a traditional group (TRG; n = 12), rest redistribution group (RRG; n = 13), or control group (n = 10). The training program was conducted with the bench press exercise and lasted 6 weeks (2 sessions per week): TRG—6 sets × 5 repetitions with 3 minutes of interset rest; RRG—1 set × 30 repetitions with 31 seconds of interrepetition rest. The total rest period (15 min) and load intensity (75% 1RM) were the same for both experimental groups. Subjects performed all repetitions at maximal intended velocity, and the load was adjusted on a daily basis from velocity recordings. ***Results:*** A significant time × group interaction was observed for both BP1RM and BPT30 ($P < .01$) due to the higher values observed at posttest compared with pretest for TRG (effect size [ES] = 0.77) and RRG (ES = 0.56–0.59) but not for the control group (ES ≤ 0.08). The changes in BP1RM and BPT30 did not differ between TRG and RRG (ES = 0.04 and 0.05, respectively). No significant differences in handball throwing velocity were observed between the pretest and posttest (ES = 0.16, 0.22, and 0.02 for TRG, RRG, and control group, respectively). ***Conclusions:*** Resistance-training programs based on not-to-failure traditional and rest redistribution set configurations induce similar changes in BP1RM, BPT30, and handball throwing velocity.

Keywords: bench press, cluster training, 1-repetition maximum, rest redistribution, throwing velocity

Muscular power has been related to a number of athletic performance tasks, such as sprinting, jumping, and throwing velocity.[1,2] In addition, the capacity to generate muscular power could differentiate between performance levels of athletes and between starters and nonstarters.[1,3] It is also important to note that muscular strength contributes significantly to the production of muscle power.[2] Consequently, sport professionals are constantly seeking ways to optimize training interventions to improve maximal strength and power generating capacities. Both muscular strength and power can be developed through resistance training while manipulating a wide range of variables such as exercise type and order, number of sets and repetitions, loading magnitude, rest between sets and movement velocity.[4,5] Therefore, it is important to understand the effects of different resistance training protocols on muscular strength and power adaptations.

Regardless of how a resistance training protocol is designed, maximizing movement velocity seems to be a key factor when the aim is to develop muscular strength and power.[6] For instance, Pareja-Blanco et al[7] found that a lower magnitude of velocity loss within each set (20%) was associated with similar squat maximal strength gains but greater enhancements in vertical jump height than training with a higher velocity loss (40%), despite the fact that the latter group performed 40% more repetitions during an 8-week training intervention. These results suggest that once a moderate velocity loss is achieved, performing more repetitions will not elicit further strength gains and could be detrimental for improving explosive strength. Without decreasing training loads or volume, likely the simplest and most effective way to mitigate acute fatigue and maintain high-movement velocities is to add intraset rest.[8] Although the addition of intraset rest is effective, these so-called "cluster sets" might not always be feasible from a practical perspective since they can extend total training time.[8]

One alternative to cluster set structures is to redistribute the total rest time of traditional (TR) set structures to include shorter and more frequent rest intervals.[9] This strategy, known as rest redistribution (RR), can maintain velocity and power output within individual sets compared with TR sets.[10–12] Furthermore, a recent study investigated the possibility of RR serving as a free ad hoc equivalent to commonly used velocity loss thresholds during clean pulls at multiple loads.[13] Interestingly, when rest periods of TR sets were redistributed to create short but more frequent rest periods, the number of repetitions performed within 10% and 20% velocity loss thresholds was greater ($g = 0.66–0.69$) than during TR sets. This suggests that sport professionals who are financially constrained to implement velocity loss thresholds during training could likely induce similar training stimuli by redistributing long interset rest periods and performing less repetitions during each set.

Numerous studies have showed beneficial effects of RR technique on acute performance maintenance during resistance training.[10–12] However, a few recent studies suggested that RR may

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only be effective if TR sets are performed to failure.[9,14,15] Although the body of evidence regarding the acute responses of RR technique is continually growing, fewer studies have investigated muscular strength and power adaptations after utilizing RR in a training environment.[16–23] For instance, Lawton et al[19] did not find superior strength and power training adaptations using the RR technique after 6 weeks of bench press (BP) training. Similarly, Morales-Artacho et al[21] reported similar increments in maximal force and power capacities for TR and RR set configurations after 3 weeks of jump squat training. However, Hansen et al[18] reported greater peak power outputs during the squat jump exercise after 8 weeks of training, and Oliver et al[20] found RR to be more effective than TR sets in provoking both strength and power adaptations after 12 weeks of training. Collectively, the effects of RR on maximal strength and power training adaptations are unclear, and further research is evidently needed.

Therefore, we designed a longitudinal study to elucidate whether the gains in maximal strength and explosive actions performance induced by resistance training programs conducted with the BP exercise could be influenced by the set configuration. Specifically, the main aim of the present study was to compare the effects of 2 upper-body strength training programs differing only in the set configuration (TR and RR) on the BP 1-repetition maximum (BP1RM), BP throw peak velocity against 30 kg (BPT30), and handball throwing velocity (HTV). As a secondary aim, we explored the association of (1) HTV with BP1RM and BPT30 before and after training and (2) the percentage change in HTV with the percentage change in BP1RM and BPT30. Given that previous acute studies conducted with the BP exercise have revealed small differences in mechanical variables between RR and not-to-failure TR set configurations,[14,15] we hypothesized that the gains in BP1RM, BPT30, and HTV would be comparable for both experimental groups (traditional group [TRG] and rest redistribution group [RRG]) in comparison with a control group (CG). A positive association was expected between the BP1RM and BPT30 with HTV before and after training,[1,24] although the lack of similar studies did not allow us to hypothesize whether the percentage change in BP1RM and BPT30 would be significantly correlated with the percentage change in HTV.

Methods

Subjects

A total of 39 recreationally resistance trained men volunteered to participate in this study. Subjects were randomly assigned to a TRG (n = 13), RRG (n = 13), and CG (n = 13). However, 4 subjects (1 from TRG and 3 from CG) were not considered for statistical analyses because they failed to complete the whole experiment protocol. The general characteristics of the subjects used for statistical analyses, who completed the study protocol without missing any sessions, were the following: TRG—n = 12, age = 21.0 (2.5) years, body mass = 73.4 (9.2) kg, height = 1.75 (0.05) m; RRG—n = 13, age = 20.3 (3.1) years, body mass = 75.0 (10.6) kg, height = 1.72 (0.05) m; and CG—n = 10, age = 22.2 (2.1) years, body mass = 73.8 (14.3) kg, height = 1.70 (0.05) m.

All subjects reported they were healthy, physically active, and had experience with BP training, but none of them were professional athletes. Subjects were instructed not to perform additional upper-body strength training over the course of the study. All subjects were informed about the study procedures and signed a written informed consent form before the commencement of the study. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the institutional review board of the University of Granada (935/CEIH/2019).

Study Design

The present study used a controlled longitudinal pre–post design with random assignment of the subjects to 3 parallel groups (2 experimental [TRG and RRG] and 1 control [CG]). The study protocol consisted of 15 sessions that were performed during an 8-week period: 2 pretests (week 1), 12 training sessions (weeks 2–7; only for TRG and RRG), and 1 posttest (week 8). All sessions were separated by at least 48 hours of rest and were performed at a consistent time of the day for individual subjects (± 1 h).

Testing Procedures

Subjects reported to the laboratory after refraining from strenuous exercise for a minimum of 48 hours. Their body mass (Tanita BC 418 segmental; Tanita Corp, Tokyo, Japan) and height (Seca 202; Seca Ltd, Hamburg, Germany) were assessed in the first testing session. The warm-up consisted of 5 minutes of jogging, dynamic stretching exercises, 10 push-ups, and 5 repetitions of the BP throw (BPT) exercise performed in a Smith machine against 20 kg. After warming up, subjects rested for 3 minutes, and then they performed these tests in the following order.

Handball Throwing Velocity. Explosive strength production was evaluated on an indoor court using a 7-m standing handball throw. A Stalker Acceleration Testing System II radar device (model: Stalker ATS II; Applied Concepts, Dallas, TX) was used to determine HTV. Subjects were instructed to throw a standard handball size III ball (mass = 480 g; circumference = 58 cm) toward the radar device at the maximal possible velocity. The radar device was positioned 2 m behind the net that stopped the ball at a height of 1 m above the ground. Subjects were positioned at a distance of 5 m from the radar device. At least 3 submaximal throws were performed as a part of the specific warm-up until subjects felt prepared for the maximal HTV assessment. Subsequently, they performed 4 maximal throws with the dominant arm separated by 30 seconds. The average value of the 3 best trials was used for statistical analyses. A researcher provided HTV feedback immediately after each trial and ensured that all throws were performed using a standard 7-m standing handball throw technique (front foot remained in contact with the ground). The throw was repeated if it was not executed with an appropriate technique.

BP Throw Peak Velocity Against 30 kg . Subjects performed 3 trials of the BPT exercise separated by 15 seconds against an external load of 30 kg. Subjects were instructed to throw the barbell as high as possible, and 2 spotters were responsible for catching the barbell during its downward movement. Barbell velocity was recorded by a linear velocity transducer (T-Force System; Ergotech, Murcia, Spain) at a frequency of 1000 Hz. The highest peak concentric velocity of the 3 trials was used for statistical analyses. The BPT and BP exercises were always performed in a Smith machine (FFittech, Taipei, Taiwan) using the touch-and-go and 5-point body contact position technique (head, upper back, and buttocks firmly on the bench with both feet flat on the floor). Subjects were allowed to self-select the grip width. The position of the bench was adjusted so that the vertical projection of the bar corresponded to each subject's intermammary line.

BP 1-Repetition Maximum. The BP1RM was determined through an incremental loading test. The initial load was 30 kg for all subjects, and it was increased in increments of 20 to 1 kg until the 1RM load was reached. The increase of the load was decided by consensus between an experienced researcher and the subject being tested. The load was increased until subjects failed to complete a repetition, and the last successful attempt was considered his 1-repetition maximum (1RM). Subjects performed 1 to 2 repetitions per load, and the recovery time between attempts was at least 5 minutes.

Training Procedures

The intervention consisted of 12 training sessions (6 wk × 2 sessions per week). Each training session lasted about 30 minutes and was preceded by the following standardized warm-up: 5 minutes of jogging, dynamic stretching exercises, 10 push-ups, and 1 set of 10, 5, and 2 repetitions of the BP exercise performed in a Smith machine against the 35% 1RM, 55% 1RM, and 75% 1RM, respectively. The TRG performed 6 sets of 5 repetitions with 3 minutes of interset rest; while the RRG performed 1 set of 30 repetitions with 31 seconds of interrepetition rest. The total rest period (15 min) and load intensity (75% 1RM) were the same for both groups. The BP exercise was performed in a Smith machine. The mean velocity of the bar was measured with a linear velocity transducer (T-Force System; Ergotech), and the load was modified on a daily basis from velocity recordings to match the desired %1RM. Specifically, the individualized load–velocity relationship was determined in the pretest during the 1RM testing procedure, and the mean velocity associated with the 75% 1RM was prescribed in all training sessions. A researcher verbally encouraged the subjects to perform all repetitions at the maximum possible velocity and provided velocity feedback after each repetition. The load was modified (if needed) after every set (for TRG) or after every repetition (for RRG) to match the desired training velocity (ie, mean velocity associated with the 75% 1RM). However, movement velocity during training was not recorded since the modification of the load within sessions would increase the complexity of the analysis of the behavior of this variable during training.

Statistical Analyses

Descriptive data are presented as means (SDs). Reliability of BP1RM, BPT30, and HTV was assessed from the data collected in the 2 pretest sessions through paired sample t test, the Hedge g effect size (ES), the coefficient of variation, and the intraclass correlation coefficient (model 3.1) using a custom spreadsheet.[25] The normal distribution of the data and the homogeneity of variances were confirmed by the Shapiro–Wilk test and Levene test, respectively ($P > .05$). A mixed model analysis of variance (ANOVA) was applied to the BP1RM, BPT30, and HTV with the "training group" (TRG vs RRG vs CG) as between-subject factor and "time" (pretest 2 vs posttest) as within-subject factor. The magnitude of changes were assessed through the partial eta squared (η_p^2) for the ANOVAs and the Hedge g ES with 95% confidence intervals (95% CI) for pairwise comparisons. Standardized differences (ES and 95% CI) were calculated using the pretest SD for within-group comparisons and the pretest pooled SD for between-group comparisons. The scale used to quantify the magnitude of the ES was as follows: negligible (<0.20), small (0.20–0.49), moderate (0.50–0.79), and large (≥0.80). The relationship of HTV with the BP1RM and BPT30 was quantified through the Pearson correlation coefficient (r). A post hoc power analysis was calculated for the interactions of the ANOVAs using the G*Power software (version 3.1.9.4; Heinrich Heine University, Düsseldorf, Germany) considering a medium ES of 0.25, an alpha of .05, total sample size of 35 subjects, 3 groups, 2 measurements, and the correlations between repeated measures of .895 for BP1RM, .806 for BPT30, and .909 for HTV. Statistical analyses were performed using the software package SPSS (version 22.0; IBM Corp, Chicago, IL). Statistical significance was set at $P < .05$.

Results

All dependent variables (BP1RM, BPT30, and HTV) were obtained with a high reliability (coefficient of variation < 3% and intraclass correlation coefficient > .90; Table 1). No significant between-groups differences were observed at pretest for any dependent variable ($P \geq .65$). The ANOVA applied on BP1RM revealed a significant time × group interaction ($F_{2,32} = 14.4$, $P < .01$, $\eta_p^2 = .474$, statistical power = 1.00) due to higher values at posttest compared with pretest for TRG ($P < .01$; ES = 0.77; 95% CI, 0.39 to 1.25) and RRG ($P < .01$; ES = 0.59; 95% CI, 0.27 to 0.98) but not for CG ($P = .66$; ES = −0.03; 95% CI, −0.33 to 0.26). The ANOVA applied on BPT30 also revealed a significant time × group interaction

Table 1 Magnitude of the BP1RM, BPT30, and HTV From the 2 Consecutive Pretest Trials and the Posttest Trial for the TRG, RRG, and CG

					Reliability (pretest 1 vs pretest 2)			
Variable	Group	Pretest 1	Pretest 2	Posttest	P	ES	CV (95% CI)	ICC (95% CI)
BP1RM, kg	TRG	68.5 (8.6)	68.8 (9.2)	76.3 (8.0)*	.84	0.004	1.69% (1.37%–2.21%)	.99 (.98–1.00)
	RRG	68.9 (13.9)	68.6 (13.3)	76.7 (12.0)*				
	CG	68.9 (17.1)	69.2 (16.1)	68.6 (13.1)				
BPT30, $m \cdot s^{-1}$	TRG	1.64 (0.20)	1.64 (0.20)	1.80 (0.17)	.46	0.024	2.32% (1.88%–3.04%)	.98 (.97–.99)
	RRG	1.65 (0.33)	1.66 (0.31)	1.84 (0.29)				
	CG	1.64 (0.34)	1.66 (0.34)	1.69 (0.33)				
HTV, $km \cdot h^{-1}$	TRG	64.2 (6.4)	64.5 (5.9)	65.5 (6.3)	.44	0.043	2.03% (1.64%–2.66%)	.95 (.90–.97)
	RRG	63.5 (4.8)	63.7 (4.8)	64.9 (5.5)				
	CG	63.1 (5.9)	63.3 (6.6)	63.4 (5.0)				

Abbreviations: BP1RM, bench press 1-repetition maximum; BPT30, bench press peak velocity against 30 kg; CG, control group; CI, confidence interval; CV, coefficient of variation; ES, Cohen d effect size; HTV, handball throwing velocity; ICC, intraclass correlation coefficient (model 3.1); RRG, rest redistribution group; TRG, traditional group. Note: The reliability of the dependent variables was obtained from the data of the 2 pretest sessions for all 3 groups merged.
*Significantly different than pretest 2 ($P < .01$).

($F_{2,32} = 7.1$, $P < .01$, $\eta_p^2 = .307$, statistical power = 0.99) due to higher values at posttest compared with pretest for TRG ($P < .01$; ES = 0.77; 95% CI, 0.40 to 1.24) and RRG ($P < .01$; ES = 0.56; 95% CI, 0.26 to 0.93) but not for CG ($P = .38$; ES = 0.08; 95% CI = −0.18 to 0.35). The ANOVA applied on HTV did not reveal a significant main effect of time ($F_{1,32} = 1.4$, $P = .24$, $\eta_p^2 = .043$), group ($F_{2,32} = 0.3$, $P = .77$, $\eta_p^2 = .016$), or their interaction ($F_{2,32} = 0.3$, $P = .78$, $\eta_p^2 = .016$, statistical power = 1.00). The net training effect regarding the magnitude of the between-group changes are shown in Figure 1. Higher increases in BP1RM and BPT30 (small to moderate effects) were observed for TRG and RRG compared with CG, whereas negligible differences were observed for the remaining comparisons.

The HTV was not significantly correlated with the BP1RM or BPT30 at any time point ($r \leq .019$, $P \geq .27$; Figure 2). Similarly, the percentage change in BP1RM ($r = -.09$, $P = .61$) and BPT30 ($r = -.12$, $P = .49$) were not significantly correlated with the percentage change in HTV (Figure 3).

Discussion

This study used a longitudinal pre–post design to compare the effects of 2 upper-body resistance training programs differing only in the set configuration (TR and RR) on the BP1RM, BPT30, and HTV. The main finding revealed that the changes in all dependent variables were not influenced by the set configuration. Both resistance training programs (TR and RR) were equally effective to enhance the BP1RM and BPT30, while HTV remained unchanged for all groups. In addition, no significant correlations were found between HTV and BP performance (BP1RM and BPT30). These results suggest that BP training using a not-to-failure TR set configuration is expected to induce similar gains in maximal strength and explosive actions performance than an RR set configuration.

The main hypothesis of the present study was accepted since similar gains in BP1RM, BPT30, and HTV were observed for TRG and RRG. Although numerous studies have showed beneficial acute effects of RR on the maintenance of velocity and power output during resistance training,[10–12] TR sets in the majority of these studies were performed until or near muscular failure. In this regard, more recent studies have reported, for various exercises, rather similar acute kinetic and kinematic outcomes when comparing RR and not-to-failure TR set configurations.[9,14,15] The findings of the present study further expand on the results of previous acute studies showing no additional benefits of RR compared with not-to-failure TR sets on the development of maximal strength and explosive performance after 6 weeks of training.[16–23]

The results of the present study are in line with Lawton et al[19] who did not find significant differences between TR and RR in BPT peak power output after 6 weeks of BP training, as well as with the findings of Morales-Artacho et al[21] who did not reveal significant differences in the changes of maximal force and power capacities between TR and RR set configurations after 3 weeks of jump squat training. However, 2 previous studies have reported greater BP and back squat maximal strength gains using TR than RR set configurations.[18,19] The discrepancies between the studies could likely be explained by the different loads used in the training interventions and also the proximity to failure within training sets. More specifically, heavier loads were used by Lawton et al[19] (80%–105% 6RM) and Hansen et al[18] (80%–95% 1RM) compared with the present study (75% 1RM) and Morales-Artacho et al[21] (20% 1RM). Similarly, the repetitions during TR were only performed near to muscular failure in the studies of Lawton et al[19] and Hansen et al[18] This suggests that fatigue-induced decrease in movement velocity, often experienced during TR, may be useful in inducing strength gains likely because it results in an increase in time under tension and myoelectrical activity toward the end of a set.[26–28] Collectively, when training loads are not heavy (>80% 1RM), and repetitions are not performed until or near muscular failure, set configurations do not seem to affect maximal strength and explosive action performance adaptations.

It is widely accepted that HTV is one of the most decisive factors in sports such as baseball[29] and team handball.[1] In addition, a growing body of research now suggests that, besides technical factors, muscular strength and power are of a great importance for HTV.[1,24,29] For instance, Marques et al[24] found significant correlations ($r = .64$) between BP1RM and HTV in elite male handball players, whereas similar correlations were reported by Gorostiaga et al[1] between HTV and BP power output ($r = .72$). However, this was not the case in the present study since no significant correlations were found between HTV and BP1RM nor BPT30. This anomaly could be explained by the study of Gorostiaga et al[1] who examined the influence of BP1RM strength on HTV in elite and amateur male handball players. The authors reported that although a significant and strong relationship between BP1RM and HTV was observed for the elite group, no significant relationships were

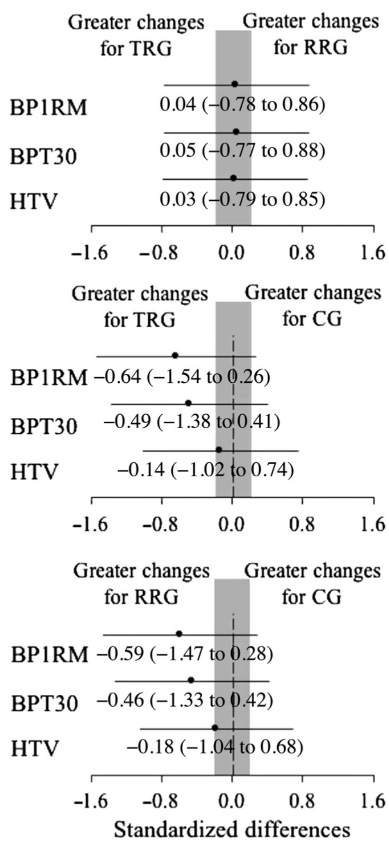

Figure 1 — Standardized differences (95% confidence intervals) of the changes in BP1RM, BPT30, and HTV between the TRG and RRG (upper panel), TRG and CG (middle panel), and RRG and CG (lower panel). The gray area represents the negligible effect size of the difference (ie, standardized differences ranging from −0.20 to 0.20). BP1RM indicates bench press 1-repetition maximum; BPT30, bench press peak velocity against 30 kg; CG, control group; RRG, rest redistribution group; HTV, handball throwing velocity; TRG, traditional group.

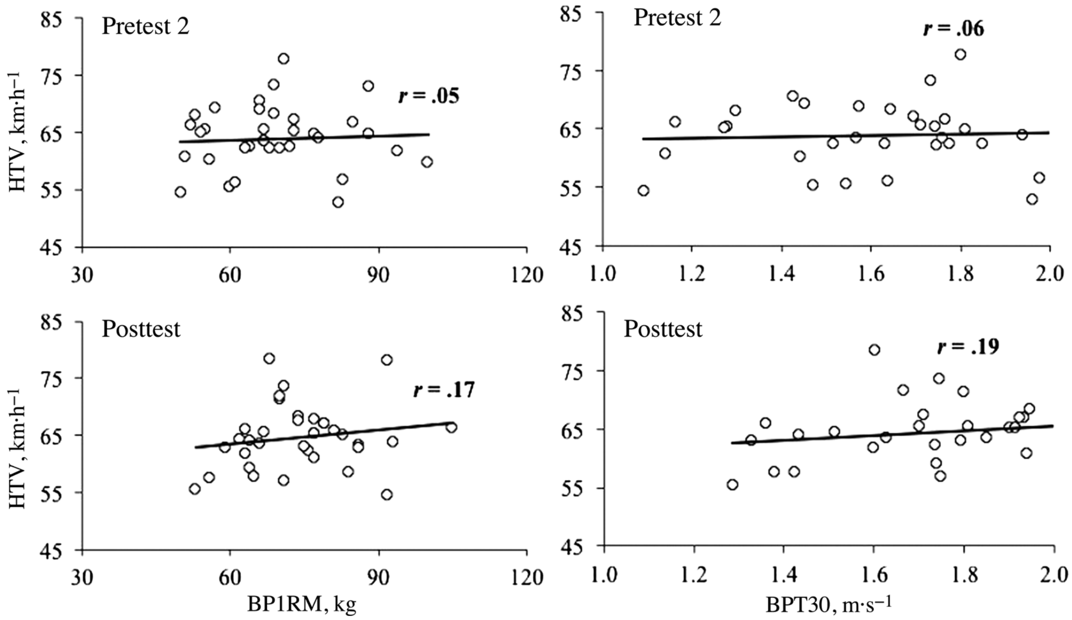

Figure 2 — Relationship of HTV with the BP1RM (left panels) and BPT30 (right panels) at pretest 2 (upper panels) and posttest (lower panels). BP1RM indicates bench press 1-repetition maximum; BPT30, bench press peak velocity against 30 kg; HTV, handball throwing velocity.

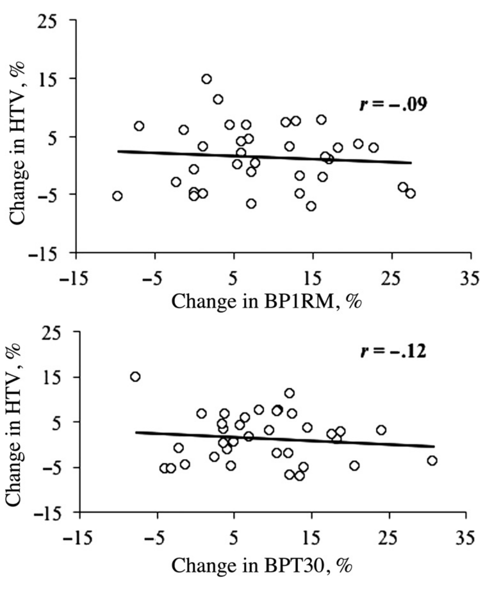

Figure 3 — Relationship of the change in HTV with the change in BP1RM (upper panel) and the change in the BPT30 (lower panel). BP1RM indicates bench press 1-repetition maximum; BPT30, bench press peak velocity against 30 kg; HTV, handball throwing velocity.

obtained for the amateur group. Based on these findings, Gorostiaga et al[1] concluded that HTV could be more dependent on coordination and technique than on strength and muscle power characteristics in less experienced players. The sample in the present study had even less experience with throwing sports than the amateur group recruited by Gorostiaga et al,[1] suggesting that gaining strength will not positively transfer to HTV performance if strength training is not accompanied by the supplementary technique work in this population. In addition, the lack of velocity-specific training in the present study could also explain the absence of improvement in HTV performance since the training program was focused on the force part of the force–velocity relationship (ie, 75% 1RM). Therefore, future studies should examine whether the addition of velocity-specific loading magnitudes (ie, <50% 1RM) and exercises (ie, BPT) using both TR and RR set configurations could facilitate HTV performance adaptations.

A positive methodological aspect of this study is that velocity recordings were used to prescribe the load in every training session based on subjects' day-to-day readiness, whereas all studies that previously examined the effect of TR and RR set configurations on performance adaptations prescribed the loads based on the preintervention 1RM.[16–19,21] However, a limitation was that the mechanical performance or metabolic involvement of the training sessions were not compared between TRG and RRG, which would be beneficial in determining the differences between the training conditions. Importantly, velocity loss and velocity maintenance during the sessions could not be compared because the loads were modified (if needed) within the session to ensure that subjects exercise at a constant intensity (%1RM). Another limitation is that subjects did not perform any sets to failure during the testing or training procedures, and, therefore, the maximum number of repetitions (ie, intensity of effort) that can be completed with the load used in training was not determined. It is also plausible that redistributing rest periods of TR to create RR with more than 1 repetition per set would have allowed for greater training adaptations for the RRG,[30] but this should be explored in future studies. Finally, this study needs to be replicated with athletes experienced in throwing sports (eg, team handball) to elucidate whether the lack of association between the changes in BP1RM and BPT30 and the changes in HTV reported in this study can be extrapolated to a trained population.

Practical Applications

Because TR (not performed to failure) and RR set configurations induced comparable gains in performance, the use of TR sets may be advantageous because it is simpler for the coach to organize the training, especially when working with large groups of athletes who have to share the same training equipment. Finally, coaches should not use the BP1RM nor BPT30 as an indicator of throwing performance in subjects not specialized in throwing sports.

Conclusions

The 6-week resistance training programs based on TR and RR set configurations were equally effective at improving BP performance (BP1RM and BPT30), although none of the groups improved HTV performance. The lack of significant correlations between HTV and BP performance (ie, BP1RM and BPT30) highlights that they represent disparate physical capacities in subjects not specialized in throwing sports. Collectively, these results suggest that BP training using a simpler not-to-failure TR set configuration is expected to induce similar gains in maximal strength and explosive actions performance than RR set configurations.

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