OPEN ACCESS
Scholars International Journal of Anatomy and Physiology
Abbreviated Key Title: Sch Int J Anat Physiol
ISSN 2616-8618 (Print) |ISSN 2617-345X (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Original Research Article

Acute Physiological Effects of Drop Set on IGF and GH in the Quadriceps Femoris Among Males in Kakamega County, Kenya

Robert Ouma Namango[1*], Ng'wena Gideon Magak[1], Kennedy Onyango[1]

[1]Department of Medical Physiology, Maseno University, Kenya

DOI: 10.36348/sijap.2023.v06i07.005 | **Received:** 11.06.2023 | **Accepted:** 18.07.2023 | **Published:** 26.07.2023

***Corresponding author:** Robert Ouma Namango
Department of Medical Physiology, Maseno University, Kenya

Abstract

Background: Resistance training (RT) for muscle growth (hypertrophy training – HT) theoretically optimizes the mechanical tension placed on the working muscle, which may be key to activating hypertrophic mechanisms. After prolonged HT, specialized weightlifting techniques like drop set training (DS) – or lifting progressively reduced loads without recovery – may help overcome plateaus in strength and re-stimulate hypertrophy, but physiological evidence to potentially support this hypothesis or the efficacy of implementing an acute drop set protocol in comparison to maintaining a standard hypertrophy training program is lacking. ***Objective:*** This objective of this study was to assess the levels of plasma growth hormone, and IGF during drop set and concentric exercises. ***Methods:*** The study used a randomized controlled, counterbalanced, repeated measures design. A repeated measures design was used to minimize the inter-individual variability of the hypertrophic response to resistance training. Thirty young males participated in a randomized, counterbalanced, within-subjects design, a DS protocol (4 sets, 4 loads/set, 75-30% 1RM, minimal recovery between loads, 3-minute recovery intervals between sets) and, separated by at least 7 days, a HT protocol (4 sets, 75% 1RM, 3-minute recovery intervals between sets). Data was analyzed using a 2 (Training Type: DS, HT, levels of quadriceps muscle hypertrophy) ´ 2 (Time: pre-exercise, post-exercise) repeated measures ANOVA to test the differences in concentrations of IGF-1 and GH during DS and HT at the specified time points. ***Results:*** The study found that there was a significant difference in IGF 1 levels before and after the exercise for both groups (Drop set and concentric exercise), with a p-value of .007. The interaction effect between the within-subjects factor (IGF 1 pre and post) and group was also significant. The results showed that there was a significant difference in GH levels before and after the exercise for both groups (Drop set and concentric exercise), with a p-value of < .001. For the Drop set group, GH pre was also significantly lower than GH post. It can be concluded that both the drop set and concentric exercise techniques have an impact on the levels of IGF 1, and GH in the quadriceps femoris. The study recommends that physical trainers and fitness professionals should consider using the Drop set exercise technique in their training programs for clients who are looking to improve their performance.

Keywords: Drop sets, IGF (Insulin-like Growth Factor), GH (Growth Hormone), Quadriceps Femoris, Resistance training, Muscle hypertrophy, Anabolic response, Exercise-induced hormone response.

BACKGROUND

Resistance training (RT) is implemented in order to enhance athletic performance and body aesthetics, as well as maintain or improve neuromuscular functioning and individual health status (Bjersing *et al.*, 2017; Folland & Williams, 2007). As the hypertrophic adaptations triggered by these mechanisms occur slowly and progressively during RT, many athletes eventually experience training plateaus, where standard RT protocols eventually fail to elevate the net protein synthetic rate, thereby reducing expected gains in strength and/or hypertrophy (Peterson *et al.*, 2005; Schoenfeld, 2012). Indeed, studies have shown reductions in response to RT in MPS, strength, and endurance with long-term repeated exposure (Gacesa *et al.*, 2013; Phillips *et al.*, 1999). Training techniques such as pyramids, supersets, forced repetitions, and drop sets (Hackett & Amirthalingam, 2015; Heavens *et al.*, 2014; Kelleher *et al.*, 2010; Robbins *et al.*, 2010; Schoenfeld, 2011) are designed to force the athlete to increase training volume and induce more mechanical

and metabolic stress on a working muscle group than standard, multiple set hypertrophy training (HT).

Research examining acute and chronic changes in circulating anabolic hormonal concentrations in response to hypertrophy training (HT) have reported increases (Izquierdo *et al.*,2009; West *et al.*,2010), decreases (Raastad*et al.,* 2000), and no changes (West *et al.*,2010) in levels of GH (Izquierdo *et al.*,2009; West *et al.*,2010), testosterone (Izquierdo *et al.*,2009; Raastad *et al.*,2000; West *et al.*,2010) and IGF-1 (West *et al.*,2010), with or without resultant muscle growth. Interestingly, research in both animal and human models indicates that an IGF-1 isoform synthesized locally in working skeletal muscle (also known as mechano-growth factor) is the most likely candidate to exert a hypertrophic effect with RT, and is thought to most likely involve satellite cell (skeletal muscle stem cell) activation and proliferation, as well as replenishment of the stem cell pool (Goldspink, 2005; Stewart & Pell, 2010). As HT may be optimizing mechanical tension and Time under tension (TUT), the volume and mechanical overload associated with contractions to failure has been shown to trigger anabolic hormone release, upregulate muscle protein synthesis (MPS), and promote satellite cell activity (Pearson & Hussain, 2014; Rasmussen & Phillips, 2003; Schoenfeld, 2013), especially when the exercise involves unaccustomed movements, intensity, or duration.

Concurrently, HT has also been shown to elevate skeletal muscle cytokine release (e.g., fibroblast growth factor, interleukin (IL)-6, 10, 15) (Schoenfeld, 2012), which has been suggested to play a potential role in the signaling, repair, and hypertrophy of damaged muscle tissue after intense resistant training (RT). In particular, muscle contraction-induced expression of IL-6 is minimal in non-overloaded muscles, but readily detectable intramuscularly in overloaded muscles (Serrano*et al.,* 2008). Elevations of IL-6 within muscle and in circulation have also been shown acutely post-exercise (Pedersen & Febbraio, 2012), especially as training volume increases (*et al.,* 2010), and are correlated with hypertrophy over long term training (Mitchell *et al.*,2013). IL-6 is suggested to mediate skeletal muscle hypertrophy via activation of satellite cells, which are capable of differentiating into muscle cells and fusing into existing muscle fibers (Serrano *et al.,* 2008). This provides the muscle fiber with the additional cellular machinery required to support increased MPS rates and subsequent muscle hypertrophy. Thus, maximizing IL-6 expression in working muscle tissue could expedite the hypertrophic process.

In 2003, Goto, Sato, & Takamatsu had young male, resistance trained subjects perform a single drop set with only one load reduction 30 seconds after the completion of a ST protocol consisting of 5 sets of leg extensions at 90% 1RM (repetition maximum) with 3-minute recovery intervals. The single drop set load reduction was set at either 50% 1RM (DS50), 70% 1RM (DS70), or an additional set at 90%1RM (DS90) to determine the effect of the inclusion of a single drop set with one load reduction on selected physiological parameters. The blood lactate (BLa) concentrations of the light DS conditions (DS50 and DS70) were significantly elevated compared to the DS90 and ST protocols (Goto*et al.,* 2003). They also reported a significant acute GH response to the light DS (DS50 and DS70) compared to ST alone (Goto *et al.,* 2003). A significant positive correlation between changes in [GH] and training volume ($r = .8$, $p < .05$) was also observed (Goto *et al.,* 2003). Their data clearly indicated the importance of a significantly reduced load during DS, and that eliminating recovery intervals without reducing load (as in DS90) does not provide the same benefits that DS has shown in previous work (Choi *et al.*,1998a; 1998b). This is likely due to the additional volume and TUT provided by lifting lighter loads for more repetitions in the DS50 and DS70 conditions.

Also, the data suggest that performing a standard ST protocol followed by a single drop set with one load reduction elevates growth hormone (GH) and La when the load is adequately light. Interestingly, Schoenfeld (2011) and Willardson *et al.*,(2010) have also suggested the increased volume that DS confers, and not the drop set technique itself, may explain the observed differences. However, increases in GH may also be attributed to the increased metabolic stress (correlation between [GH] and [BLa]: $r = .75$, $p < .05$ – (Goto *et al.*,2003) in the more heavily recruited Type II muscle fibers conferred by the minimal recovery interval in tandem with high volume provided by the drop set (DS) protocols. After their discovery of the acute GH responses following a standard ST protocol versus various single DS protocols in 2003, Goto *et al.*,(2004) compared ST and their most potent DS protocol (DS50 – see Figure 6A) to the DS protocol employed by Choi *et al.*,(1998b) (3 drop sets, each with 2 load reductions) on changes in acute [GH].

[GH] followed a dose-response pattern, in this case, increasing with training volume (ST – 5 sets + 0 drop sets; DS50 – ST + 1 drop set with 1 load reduction; DS – 3 drop sets each with 2 load reductions). These results are consistent with the suggestion that the magnitude of the GH response to RT is dependent on training volume and the length of recovery intervals employed in the program (Fransen & Kravitz, 2011). Taking the reported ST [GH] value as a "baseline" measurement for standard RT protocols, this result may suggest that DS may be effective in creating an amplified response to typical training programs, which might be suitable for prescription when strength gains plateau. Although recent research has reported

increases, decreases, as well as no changes in GH responses to RT, which has led some to question the physiological relevance of changes in [GH] during RT (Izquierdo *et al.*,2009; West *et al.*,2010), it should be noted that it is feasible that DS may influence changes in other relevant hormones or physiological activity yet to be studied. For example, GH has been suggested to mediate insulin growth hormone (IGF-1) activity (Fransen & Kravitz, 2011) and activate satellite cell proliferation as well as upregulate MPS (Goldspink, 2005).

Collectively, drop sets data report an increase in tension under tension, elevated anaerobic metabolic byproducts, and enhanced anabolic hormone production as compared to standard strength training protocols. The research suggests that resistance training using drop sets may stimulate the potential mechanisms responsible for hypertrophy and allow the subject to overcome strength and hypertrophy training plateaus often observed over the course of standard resistance training programs. However, such data is very critical to the exercise regimes prescription at the levels of muscle training, the purpose of this study is to assess the acute physiological effects of drop sets to a standard training protocol using leg extensions in the quadriceps femoris

METHODS

Study Design

The study was a randomized, counterbalanced, repeated measures design. A repeated measures design will be used to minimize the inter-individual variability of the hypertrophic response to resistance training (Kelleher *et al.*, 2010; West *et al.*, 2010), which may be very large (Hubal *et al.*, 2005). The repeated measures design allowed all participants to participate in both conditions and counterbalancing controlled for any potentially confounding carry-over effects due to testing order.

Ethical and logistical issues

This study involved human subjects and institutions; it was mandatory to ensure that human dignity was upheld. Ethical clearance was sought from MUSERC followed by the research license from National Commission of Science Technology and Innovation (NACOSTI). The principle of autonomy was exercised through the process of free and informed consent. The purpose of the study was explained to the participants so that they can make their own informed choices. Participants' personal information and testing results were stored confidentially. Digital data was secured on a password-protected computer and backed up on an external hard drive.

Participants

This study recruited 30 male participants between the ages of 18-28 who have at least 2 months of resistance training (RT) experience at least twice per week (Charro *et al.*, 2010; Heavens *et al.*, 2014; Kelleher *et al.*, 2010). This population was chosen because they are relatively healthy and familiar with the feelings of regular exercise (e.g., muscle soreness, understand feeling of higher exercising heart rates), while demonstrating moderate fitness levels. Participants were recruited from the local community via posters, email, social media, and word of mouth.

Sample Strategy and Size

Sample size was calculated using software G-power. Using a repeated measures design, the minimum sample size necessary to detect significant changes will be 30 participants, with alpha set at 0.05, power set at 0.7, and effect size estimated at 0.8.

Protocol

Following blood sampling and a 10-minute break, the participant's resting heart rate and RPE will be recorded. Subsequently, they will complete a warmup consisting of 2 sets of 12 repetitions of lightly loaded (30% 1RM) leg extensions. Initial quadriceps strength will be quantified by completion of three 3-second MVIC tests. After 5 minutes of additional rest to ensure full recovery, participants assigned to Group 1 will perform the DS protocol, and participants assigned to Group 2 will perform the HT protocol. Participants performed 4 sets of leg extensions at 75% 1RM – chosen because this load resides within the traditional HT load (70-85% 1RM) and repetition range (6-12 repetitions) (Bird et al., 2005). Thus, they were instructed to complete 8-12 repetitions per set, or as many repetitions as possible until momentary muscular failure. The total number of successful and unsuccessful repetitions were recorded.

A successful/unsuccessful repetition will be operationally defined as the ability/inability to move the given load through the previously defined range of motion. Starting intensity for drop sets (DS) was equated to 75% 1RM while aiming to complete 8-12 repetitions, or as many repetitions as possible until momentary muscular failure. A starting intensity of 75% 1RM was chosen since it is the lowest reported starting intensity for drop sets in the available literature (Choi *et al.*, 1998b; Goto *et al.*, 2004; Melibeu Bentes *et al.*, 2012), and matches the traditional HT load (70-85% 1RM) and repetition range (6-12 repetitions) (Bird *et al.*, 2005). Participants rested only long enough after momentary muscular failure to allow the experimenter to reduce the % 1RM load and will be instructed to immediately start the next set.

Data Collection

The data collection was conducted by trained research assistants who were familiar with the study protocol. Samples were thawed on ice and analyzed for IGF-1 and GH using commercially available enzyme-linked immunosorbent assay kits (Human ELISA per

the manufacturer's instructions. Samples, standards, and controls were run in duplicate. The concentrations of all blood markers were uncorrected for changes in plasma volume since these are the concentrations to which potential target tissues would have been exposed. IGF-1 and GH were quantified per the manufacturer's instructions. Standards, blanks, and unknown samples were added to three 96-well microplates pre-coated with a monoclonal antibody specific for human IGF-1 and GH. Plasma samples were pretreated to release IGF-1 from binding proteins, and thus will be diluted by a factor of 100. The plates were washed after a 2-hour incubation period at 2-8ºC, and an enzyme-linked polyclonal antibody specific to IGF-1 and GH conjugated to horseradish peroxidase were added to the wells. Following a second 1-hour incubation period at 2-8ºC and another wash, a substrate solution was added to the wells to allow color to develop for 30 minutes in the dark. Color development was terminated by the addition of sulfuric acid. The optical density (OD) of each well was read at 450 nm on a microplate reader. Software capable of generating a log-log curve fit (My Assay Software) was used to create a standard curve. A background correction step will be included in the analysis (i.e., the mean OD of the control sample will be subtracted from the mean OD of the standards and unknown samples). The concentrations of the unknown samples (in ng/mL) were interpolated from the standard curve and multiplied by the dilution factor 100.

Statistical Analysis

Data was analyzed using a 2 (Training Type: DS, HT) ´2 (Time: pre-exercise, post-exercise) and the data met all the assumptions for parametric test, repeated measures ANOVA was used to test the differences in concentrations of IGF-1 and GH during DS and HT at the specified time points. When data did meet the assumption for normal distribution it was converted by Log 10 conversation. Most of the data met the assumption of sphericity, however, when the assumption of sphericity was violated, F statistics was reported using the Greenhouse-Geisser Epsilon correction factor. Mean differences were considered statistically significant where $p < .05$. When a significant F value was found, pair-wise comparisons were performed using a Bonferroni post hoc procedure. A partial eta-squared test (η2p) was performed on each interaction to test the effect size for any statistical effect found. All data including descriptive statistics was presented as means and standard errors (SE).

Strengths and Limitations

The strengths of this study is that the study design controlled for extraneous variables and reduced the likelihood of false results. The use of two groups (Drop set and concentric exercise) allowed for comparison and determination of which technique had a greater impact on IGF 1 and GH levels and hypertrophy. Some limitations in the study were; The sample size was limited and may not be representative of the population. The study only focused on the quadriceps femoris, so the results may not generalize to other muscle groups. The study only looked at the acute effects of the exercise techniques, and long-term effects were not evaluated.

RESULTS

Male participant characteristics are outlined in Table1. The observations for age had an average of 21.77 (*SD* = 1.33). The observations for height had an average of 1.72 (*SD* = 0.04). The observations for BMI had an average of 26.27 (*SD* = 1.21, Skewness = -0.18, Kurtosis = -0.87). The observations for weight had an average of 77.70 (*SD* = 1.99, Skewness = -0.19, Kurtosis = -1.42). The observations for Leg extension had an average of 207.10 (*SD* = 5.60, Skewness = -0.05, Kurtosis = -0.10). When the skewness is greater than 2 in absolute value, the variable is considered to be asymmetrical about its mean. When the kurtosis is greater than or equal to 3, then the variable's distribution is markedly different than a normal distribution in its tendency to produce outliers (Westfall & Henning, 2013).

Table 1: Summary Statistics Table for Interval and Ratio Variables

Variable	*M*	*SD*	*n*	SE_M	Min	Max	Skewness	Kurtosis
Age(years)	21.77	1.33	30	0.24	20.00	24.00	0.26	-1.04
Height(m)	1.72	0.04	30	0.007	1.68	1.79	0.12	-1.70
BMI (kg×m-2)	26.27	1.21	30	0.22	24.21	28.34	-0.18	-0.87
Weight (Kg)	77.70	1.99	30	0.36	75.00	80.00	-0.19	-1.42
Leg extension 1RM (Kg)	207.10	5.60	30	1.02	195.89	219.73	-0.05	-0.10
Note. '-' indicates the statistic is undefined due to constant data or an insufficient sample size. SE: Standard Error. m: meters. kg: kilograms. BMI: Body Mass Index. 1RM: One Repetition Maximum load.								

Levels of IGF and GH in the quadriceps femoris

Human insulin-like growth factor IGF-1

Evaluation for the presence of human insulin-like growth factor (IGF)-1 in 120 plasma samples collected pre- and post-exercise in both drop set (DS) and concentric exercise groups (CE) (Figure 1) was completed using a commercially available enzyme linked immunosorbent assay (ELISA) kit (DG100, R&D Systems, Inc., Minneapolis, MN, USA). A mixed model analysis of variance (ANOVA) with one within-subjects factor and one between-subjects factor was conducted to determine whether significant differences

exist among IGF 1 pre and IGF 1 post between the levels of group. The usual sphericity assumption does not apply when there are only two repeated measurements. To identify influential points in the residuals, Mahalanobis distances were calculated and compared to a χ^2 distribution (Newton & Rudestam, 2012). An outlier was defined as any Mahalanobis distance that exceeds 13.82, the 0.999 quantile of a χ^2 distribution with 2 degrees of freedom (Kline, 2015). There were no outliers detected in the model. The results were examined based on an alpha of .05. The main effect for group was significant, F (1, 28) = 8.41, p = .007, indicating that there were significant differences in IGF 1 pre and IGF 1 post between the levels of group. The main effect for the within-subjects factor was significant, F (1, 28) = 9.87, p = .004, indicating there were significant differences between the values of IGF 1 pre and IGF 1 post. The interaction effect between the within-subjects factor and group was significant, F (1, 28) = 7.95, p = .009, indicating that the relationship between IGF 1 pre and IGF 1 post differed significantly between the levels of group. Table 2 presents the ANOVA results.

Table 2: Mixed Model ANOVA Results

Source	*df*	*SS*	*MS*	*F*	*p*	$\eta_p 2$
Between-Subjects						
group	1	309.57	309.57	8.41	.007	0.23
Residuals	28	1,030.33	36.80			
Within-Subjects						
Within Factor	1	437.76	437.76	9.87	.004	0.26
group: Within. Factor	1	352.49	352.49	7.95	.009	0.22
Residuals	28	1,241.82	44.35			

The mean contrasts utilized Tukey post-hoc comparisons based on an alpha of .05. Tukey comparisons were used to test the differences in the estimated marginal means for each combination of between-subject and within-subject effects. For the Drop set category of group, IGF 1 pre was significantly less than IGF 1 post, t (28) = -4.21, p < .001. No other significant differences were found for group. Table 3 presents the marginal means contrasts for the Mixed Model ANOVA.

Table 3: The Marginal Means Contrasts for each Combination of Within-Subject Variables for the Mixed Model ANOVA

Contrast	Difference	*SE*	*df*	*t*	*p*
group Drop set					
IGF 1 pre - IGF 1 post	-10.25	2.43	28	-4.21	< .001
group Concentric exercise					
IGF 1 pre - IGF 1 post	-0.55	2.43	28	-0.23	.821
Note. Tukey Comparisons were used to test the differences in estimated marginal means.					

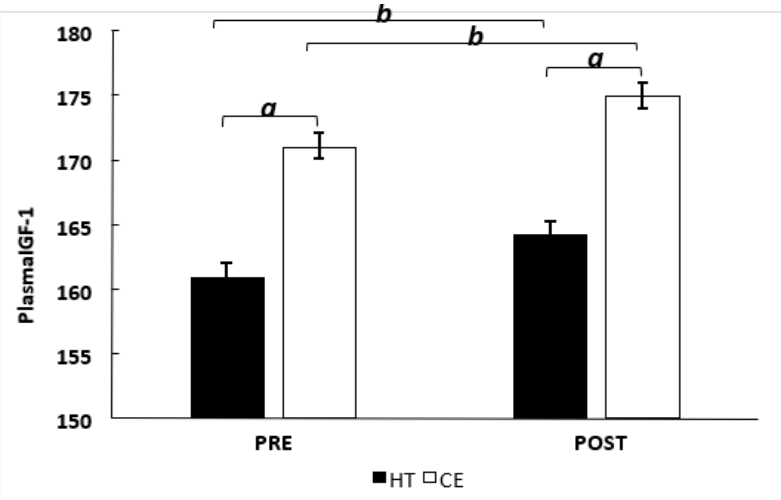

Figure 1: Changes in concentration of plasma IGF-1 (measured in nanograms per milliliter (ng/mL) before (PRE) and after (POST) exercise using concentric exercise (CE, n = 15) versus drop set training (DS, n = 15). PRE: pre-exercise. POST: post-exercise. Values are means ± SE. *a*: p < .05 between HT and CE. b: significant difference from PRE

Serum Growth Hormone (GH)

Serum GH concentrations were measured induplicate by immunoradiometric assay using standards di-luted in human serum (Nichols Institute, San Juan Capis-trano, CA). All samples for a subject were run in the same Serum GH concentrations were measured induplicate by immunoradiometric assay using standards di-luted in human serum (Nichols Institute, San Juan Capis-trano, CA). All samples for a subject were run in the same Serum GH concentrations were measured induplicate by immunoradiometric assay using standards di-luted in human serum (Nichols Institute, San Juan Capis-trano, CA). The mass of GH secreted per pulse was estimated as the area of the calculated secretory pulse (μg/l distribution volume, lv). A mixed model analysis of variance (ANOVA) with one within-subjects factor and one between-subjects factor was conducted to determine whether significant differences exist among GH pre and GH post between the levels of group. The results were examined based on an alpha of .05. The main effect for group was significant, F (1, 28) = 10,768.35, p < .001, indicating that there were significant differences in GH pre and GH post between the levels of group. The main effect for the within-subjects factor was significant, F (1, 28) = 348.99, p < .001, indicating there were significant differences between the values of GH pre and GH post. The interaction effect between the within-subjects factor and group was significant, F (1, 28) = 16.68, p < .001, indicating that the relationship between GH pre and GH post differed significantly between the levels of group. Table 4 presents the ANOVA results.

Table 4: Mixed Model ANOVA Results

Source	***df***	***SS***	***MS***	***F***	***p***	$\eta_p 2$
Between-Subjects						
group	1	3.53	3.53	10,768.35	< .001	1.00
Residuals	28	0.009	0.0003			
Within-Subjects						
Within Factor	1	0.17	0.17	348.99	< .001	0.93
group: Within. Factor	1	0.008	0.008	16.68	< .001	0.37
Residuals	28	0.01	0.0005			

The mean contrasts utilized Tukey comparisons post hoc based on an alpha of .05. For the concentric exercise category of group, GH pre was significantly less than GH post, t (28) = -10.32, p < .001. For the Drop set category of group, GH pre was significantly less than GH post, t (28) = -16.10, p < .001. Table 5 presents the marginal means contrasts for the Mixed Model ANOVA.

Table 5: The Marginal Means Contrasts for each Combination of Within-Subject Variables for the Mixed Model ANOVA

Contrast	**Difference**	***SE***	***df***	***t***	***p***
group| concentric exercise					
GH pre – GH post	-0.08	0.008	28	-10.32	< .001
group| Drop set					
GH pre – GH post	-0.13	0.008	28	-16.10	< .001
Note. Tukey Comparisons were used to test the differences in estimated marginal means.					

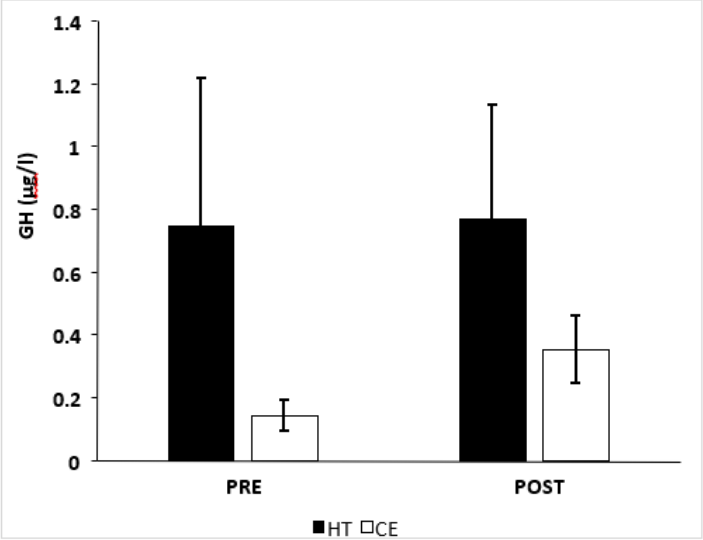

Figure 2: Changes in concentration of GH before (PRE) and after (POST) exercise using concentric training (CE, n = 15) versus drop set training (DS, n = 30). PRE: pre-exercise. POST: post-exercise. Values are means ± SE

DISCUSSION

Training plateaus are common during standard hypertrophy training (HT), which entails four sets at 75% of the lifter's one-repetition maximum load (1RM), and cause little to no muscle protein synthesis (MPS) and little hypertrophic improvements (Peterson *et al.*, 2005; Schoenfeld, 2012). Drop set training (DS) is a method used by strength and conditioning specialists to re-stimulate the hypertrophic response to resistance training (RT) by maintaining the structure of the typical HT design but adding one or more sets at progressively reduced loads also to failure before any recovery after the initial set of 10–12 repetitions to momentary muscular failure. More sets per muscle group performed during RT have been demonstrated to improve MPS intensity and duration as well as muscular growth (Burd *et al.*, 2010a; Krieger, 2010; Phillips *et al.*, 1997). By significantly increasing training volume-load (repetitions' load), time under tension (TUT), and stressing skeletal muscle metabolism compared to HT, DS protocols may provide the necessary physiological stimulus to reinitiate hypertrophic adaptations during a training plateau (Pearson & Hussain, 2014; Schoenfeld, 2011). (Folland *et al.*, 2002). This research set out to compare the immediate post-exercise release of insulin-like growth factor (IGF)-1 and growth hormone (GH) between a DS leg extension protocol and a conventional HT leg extension protocol, both of which may play a role in the hypertrophic adaptations to RT. 4 sets at 75% 1RM with 3 minutes of rest between each set was the HT regimen. The DS regimen called for four sets with three progressive load reductions each set (load range: 75-30 percent 1RM, 10 percent load decreases, 10-12 repetitions per load), for a total of 16 bouts until temporary muscle failure. No respite was taken between lighter loads, and rest periods of 3 minutes were inserted between each set. When comparing HT and DS, you can see that DS produced much higher volume-load and TUT.

Compared to previous DS studies (Choi *et al.*, 1998b; Goto *et al.*, 2003; Melibeu Bentes *et al.*, 2012), our mean volume-load data showed similar, if not larger, differences between DS and HT. Our data was also comparable to the volume generated by typical full-body HT and lower-body HT protocols (McKay *et al.*, 2009; Mitchell *et al.*, 2013; Nieman *et al.*, 2004; Phillips *et al.*, 2010). An increased hypertrophic environment may be fostered by the upregulation of muscle protein synthesis (MPS), the enhancement of local metabolic stress, and the consequent enhancement of the creation of anabolic mediators, as reported by Burd *et al.*, (2010a; 2012a). Heart rate responses, Borg ratings of perceived effort, and blood lactate (BLa) concentrations were all considerably greater in DS compared to HT with each set, reflecting the large increase in volume-load and TUT seen in DS. This suggests that the maximal activation of Type II muscle fibers would occur during the 4 DS weights lifted to failure without rest, which led to a greater exercise intensity and prompted a larger anaerobic glycolytic demand for ATP generation (Burd *et al.*, 2012a; Carpinelli, 2008). The increased [BLa] seen in DS is similar to other RT studies (Goto *et al.*, 2005; Izquierdo *et al.*, 2009) given the sole muscle group engaged and volume-load produced in our leg extension protocol, and validates the findings of prior DS research indicating a higher anaerobic energy demand (de Paula Simola *et al.*, 2015; Goto *et al.*, 2003).

CONCLUSION & RECOMMENDATION

The results showed that there was a significant difference in IGF 1 levels before and after the exercise

for both groups (Drop set and concentric exercise), with a p-value of .007. The interaction effect between the within-subjects factor (IGF 1 pre and post) and group was also significant, with a p-value of .009, indicating that the relationship between IGF 1 pre and post varied between groups. For the Drop set group, IGF 1 pre was significantly lower than IGF 1 post. The results showed that there was a significant difference in GH levels before and after the exercise for both groups (Drop set and concentric exercise), with a p-value of < .001. The interaction effect between the within-subjects factor (GH pre and post) and group was also significant, with a p-value of < .001, indicating that the relationship between GH pre and post varied between groups. For the concentric exercise group, GH pre was significantly lower than GH post. For the Drop set group, GH pre was also significantly lower than GH post.

The study recommended that physical trainers and fitness professionals should consider using the Drop set exercise technique in their training programs for clients who are looking to improve their performance. However, it is important to remember that individual differences, such as age, gender, and fitness level, should be taken into account when designing training programs. Further research is needed to confirm these findings in larger and more diverse populations. In addition, the long-term effects of the Drop set exercise technique on performance and physiological parameters should be studied.

DECLARATIONS

Funding

This study was not funded by any external funders

Competing interest

The authors declare that they have no competing interests.

Disclaimer

The findings and conclusions presented in this manuscript are those of the authors and do not necessarily reflect the official position of Maseno University.

REFERENCES

- Ahtiainen, J. P., & Häkkinen, K. (2009). Strength athletes are capable to produce greater muscle activation and neural fatigue during high-intensity resistance exercise than nonathletes. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *23*(4), 1129–1134.
- American College of Sports Medicine. (2009). American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Medicine and Science in Sports and Exercise*, *41*(3), 687–708.
- Barclay, R. D., Mackenzie, R. W., Burd, N. A., Tyler, C. J., & Tillin, N. A. (2019). The role of the IGF-1 signaling cascade in muscle protein synthesis and anabolic resistance in aging skeletal muscle. *Front. Nutrition 6*, 146.
- Bartke, A., & Darcy, J. (2017). GH and aging: pitfalls and new insights. *Best Pract. Res. Clin. Endocrinol. Metabol. 31*, 113–125.
- Bhasin, S., Storer, T. W., Berman, N., Callegari, C., Clevenger, B., Phillips, J., ... & Casaburi, R. (2001). The effects of supraphysiologic doses of testosterone on muscle size and strength in normal men. *New England Journal of Medicine*, *335*(1), 1-7.
- Bird, S. P., Tarpenning, K. M., & Marino, F. E. (2005). Designing resistance training programmes to enhance muscular fitness. *Sports Medicine*, *35*(10), 841–851.
- Bjersing, J. L., Larsson, A., Palstam, A., Ernberg, M., Bileviciute-Ljungar, I., & Löfgren, M. (2017). Benefits of resistance exercise in lean women with fibromyalgia: involvement of IGF-1 and leptin. *BMC Musculoskeletal Disord. 18*, 106.
- Buford, T. W., Cooke, M. B., & Willoughby, D. S. (2009). Resistance exercise-induced changes of inflammatory gene expression within human skeletal muscle. *European Journal of Applied Physiology*, *107*(4), 463–471.
- Burd, N. A., Andrews, R. J., West, D. W. D., Little, J. P., Cochran, A. J. R., & Hector, A. J. (2012a). Muscle time under tension during resistance exercise stimulates differential muscle protein sub-fractional synthetic responses in men. *The Journal of Physiology*, *590*(2), 351–362.
- Burd, N. A., Holwerda, A. M., Selby, K. C., West, D. W. D., Staples, A. W., & Cain, N. E. (2010a). Resistance exercise volume affects myofibrillar protein synthesis and anabolic signalling molecule phosphorylation in young men. *The Journal of Physiology*, *588*(16), 3119–3130.
- Burd, N. A., Mitchell, C. J., Churchward-Venne, T. A., & Phillips, S. M. (2012b). Bigger weights may not beget bigger muscles: evidence from acute muscle protein synthetic responses after resistance exercise. *Applied Physiology, Nutrition, and Metabolism*, *37*(3), 551–554.
- Burd, N. A., West, D. W. D., Staples, A. W., Atherton, P. J., Baker, J. M., & Moore, D. R. (2010b). Low-load high volume resistance exercise stimulates muscle protein synthesis more than high-load low volume resistance exercise in young men. *PLoS ONE*, *5*(8), e12033.
- Cannon, J., & Marino, F. E. (2010). Early-phase neuromuscular adaptations to high- and low-volume resistance training in untrained young and older women. *Journal of Sports Sciences*, *28*(14), 1505–1514.
- Carpinelli, R. N. (2008). The size principle and a critical analysis of the unsubstantiated heavier-is-

better recommendation for resistance training. *Journal of Exercise Science and Fitness, 6*(2), 67–86.

- Charro, M. A., Aoki, M. S., Coutts, A. J., Araújo, R. C., & Bacurau, R. F. (2010). Hormonal, metabolic and perceptual responses to different resistance training systems. *Journal of Sports Medicine and Physical Fitness, 50*(2), 229–234.
- Charro, M. A., Aoki, M. S., Nosaka, K., & Foschini, D. (2012). Comparison between multiple sets and half-pyramid resistance exercise bouts for muscle damage profile. *European Journal of Sport Science, 12*(3), 249–254.
- Chidi-Ogbolu, N., & Baar, K. (2019). Effect of estrogen on musculoskeletal performance and injury risk. *Front. Physiol. 9:*1834.
- Choi, J. Y., Masuda, K., & Muraoka, M. (1998a). Difference in effects between "powerup type" and “bulk-up type” strength training exercises (2) - With special reference to muscle histochemical properties and capillary supply. *Japanese Journal of Physical Fitness and Sports Medicine, 47*(2), 189–198.
- Choi, J. Y., Takahashi, H., Itai, Y., & Takamatsu, K. (1998b). The difference between effects of "power-up type" and “bulk-up type” strength training exercises - with special reference to muscle cross-sectional area, muscular strength, anaerobic power and anaerobic endurance. *Japanese Journal of Physical Fitness Sports Medicine, 47*(1), 119–130.
- Consitt, L. A., Saneda, A., Saxena, G., List, E. O., & Kopchick, J. J. (2017). Mice overexpressing growth hormone exhibit increased skeletal muscle myostatin and MuRF1 with attenuation of muscle mass. *Skeletal Muscle, 7*,17.
- Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power. *Sports Medicine, 41*(1), 17–38.
- de Paula Simola, R. Á., Harms, N., & Raeder, C. (2015). Assessment of neuromuscular function after different strength training protocols using tensiomyography. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 29*(5), 1339–1348.
- Debold, E. P. (2012). Recent insights into muscle fatigue at the cross-bridge level. *Frontiers in Physiology, 3*, 1–14.
- Deschenes, M. R., & Kraemer, W. J. (2002). Performance and Physiologic Adaptations to Resistance Training. *American Journal of Physical Medicine Rehabilitation, 81(Suppl)*, S3–S16.
- Fink, J. E., Schoenfeld, B. J., Kikuchi, N., & Nakazato, K. (2017). Acute and long-term responses to different rest intervals in low-load resistance training. *Int. J. Sports Med. 38*, 118–124.
- Fink, J., Kikuchi, N., and Nakazato, K. (2018a). Effects of rest intervals and training loads on metabolic stress and muscle hypertrophy. Clin. Physiol. *Funct. Imaging 38*, 261–268.
- Fink, J., Schoenfeld, B. J., & Nakazato, K. (2018b). The role of hormones in muscle hypertrophy. *Physician Sportsmed. 46*, 129–134.
- Fischer, C. P. (2006). Interleukin-6 in acute exercise and training: what is the biological relevance*? Exercise Immunology Review, 12*, 6–33.
- Folland, J. P., & Williams, A. G. (2007). The Adaptations to Strength Training. *Sports Medicine, 37*(2), 145–168.
- Folland, J. P., Irish, C. S., Roberts, J. C., Tarr, J. E., & Jones, D. A. (2002). Fatigue is not a necessary stimulus for strength gains during resistance training. *British Journal of Sports Medicine, 36*(5), 370–374.
- Fransen, J. C., & Kravitz, L. R. (2011). An exercise professional's guide to acute hormonal changes from resistance exercise. *ACSM's Health & Fitness Journal, 15*(6), 19–24.
- Gacesa, J. Z. P., Klasnja, A. V., & Grujic, N. G. (2013). Changes in strength, endurance, and fatigue during a resistance-training program for the triceps brachii muscle. *Journal of Athletic Training, 48*(6), 804–809.
- Gharahdaghi, N., Rudrappa, S., Brook, M. S., Idris, I., Crossland, H., & Hamrock, C. (2019). Testosterone therapy induces molecular programming augmenting physiological adaptations to resistance exercise in older men. *J. Cachexia Sarcopenia Muscle 10*, 1276–1294.
- Goldspink, G. (2005). Mechanical signals, IGF-I gene splicing, and muscle adaptation. *Physiology, 20*, 232–238.
- Goto, K., Ishii, N., Kizuka, T., & Takamatsu, K. (2005). The impact of metabolic stress on hormonal responses and muscular adaptations. *Medicine and Science in Sports and Exercise, 37*(6), 955–963.
- Goto, K., Nagasawa, M., Yanagisawa, O., Kizuka, T., Ishii, N., & Takamatsu, K. (2004). Muscular adaptations to combinations of high- and low-intensity resistance exercises. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 18*(4), 730–737.
- Goto, K., Sato, K., & Takamatsu, K. (2003). A single set of low intensity resistance exercise immediately following high intensity resistance exercise stimulates growth hormone secretion in men. *Journal of Sports Medicine and Physical Fitness, 43*(2), 243–249.
- Hackett, D. A., & Amirthalingam, T. (2015). A brief review of forced repetitions for the promotion of muscular hypertrophy. *Strength & Conditioning Journal, 37*(5), 14–20.
- Hakkinen, K., Pakarinen, A., Kraemer, W. J., Hakkinen, A., Valkeinen, H., & Alen, M. (2003). Selective muscle hypertrophy, changes in EMG

and force, and serum hormones during strength training in older women. *Journal of Applied Physiology*, *91*(2), 569-580.

- Handelsman, D. J., Hirschberg, A. L., & Bermon, S. (2018). Circulating testosterone as the hormonal basis of sex differences in athletic performance. *Endocrine Rev*. *39*, 803–829.
- Hasten, D. L., Pak-Loduca, J., Obert, K. A., & Yarasheski, K. E. (2000). Resistance exercise acutely increases MHC and mixed muscle protein synthesis rates in 78-84 and 23-32 yr olds. *American Journal of Physiology, Endocrinology and Metabolism*, *278*, E620–E626.
- Hay, I. D., & Wass, J. A. H. (2009). *Clinical endocrine oncology* - Second edition. Malden, MA: Blackwell Publishing.
- Heavens, K. R., Szivak, T. K., Hooper, D. R., Dunn-Lewis, C., Comstock, B. A., & Flanagan, S. D. (2014). The effects of high intensity short rest resistance exercise on muscle damage markers in men and women. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *28*(4), 1041–1049.
- Hermansen, K., Bengtsen, M., Kjær, M., Vestergaard, P., & Jørgensen, J. O. L. (2017). Impact of GH administration on athletic performance in healthy young adults: a systematic review and meta-analysis of placebo-controlled trials. *Growth Hormone IGF Res. 34*, 38–44.
- Hooper, D. R., Kraemer, W. J., Focht, B. C., Volek, J. S., DuPont, W. H., & Caldwell, L. K. (2017). Endocrinological roles for testosterone in resistance exercise responses and adaptations. *Sports Med. 47*, 1709–1720.
- Hubal, M. J., Gordish-Dressman, H., Thompson, P. D., Price, T. B., Hoffman, E. P., & Angelopoulos, T. J. (2005). Variability in muscle size and strength gain after unilateral resistance training. *Medicine and Science in Sports and Exercise*, *37*(6), 964–972.
- Izquierdo, M., Ibañez, J., Calbet, J. A. L., Navarro-Amezqueta, I., González-Izal, M., & Idoate, F. (2009). Cytokine and hormone responses to resistance training. *European Journal of Applied Physiology*, *107*, 397–409.
- Kamen, G. (2004). Neural issues in the control of muscular strength. *Research Quarterly for Exercise and Sport*, *75*(1), 3–8.
- Kelleher, A. R., Hackney, K. J., Fairchild, T. J., Keslacy, S., & Ploutz-Snyder, L. L. (2010). The metabolic costs of reciprocal supersets vs. traditional resistance exercise in young recreationally active adults. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *24*(4), 1043–1051.
- Kraemer, W. J., & Ratamess, N. A. (2005). Hormonal responses and adaptations to resistance exercise and training. *Sports Medicine*, *35*(4), 339–361.
- Kraemer, W. J., Fry, A. C., Warren, B. J., Stone, M. H., Fleck, S. J., & Kearney, J. T. (1998). Acute hormonal responses in elite junior weightlifters. *International Journal of Sports Medicine*, *19*(7), 526-531.
- Kraemer, W. J., Marchitelli, L., Gordon, S. E., Harman, E., Dziados, J. E., Mello, R. (1990). Hormonal and growth factor responses to heavy resistance exercise protocols. *Journal of Applied Physiology*, *69*(4), 1442–1450.
- Kraemer, W. J., Ratamess, N. A., & Nindl, B. C. (2017). Recovery responses of testosterone, growth hormone, and IGF-1 after resistance exercise. *J. Appl. Physiol. 122*, 549–558.
- Kraemer, W. J., Ratamess, N. A., Hymer, W. C., Nindl, B. C., & Fragala, M. S. (2020). Growth Hormone (s), testosterone, insulin-like growth factors, and cortisol: roles and integration for cellular development and growth with exercise. *Front. Endocrinol. 11*, 33.
- Krieger, J. W. (2010). Single vs. multiple sets of resistance exercise for muscle hypertrophy: a meta-analysis. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *24*(4), 1150–1159.
- Lamb, G. D. (2000). Excitation-contraction coupling in skeletal muscle: comparisons with cardiac muscle. *Clinical and Experimental Pharmacology and Physiology*, *27*(3), 216–224.
- Lamb, G. D., & Stephenson, D. G. (2006). Point: lactic acid accumulation is an advantage during muscle activity. *Journal of Applied Physiology*, *100*(4), 1410–1414.
- MacIntosh, B. R., Holash, R. J., & Renaud, J.M. (2012). Skeletal muscle fatigue - regulation of excitation-contraction coupling to avoid metabolic catastrophe. *Journal of Cell Science*, *125*(9), 2105–2114.
- McCurdy, K., Langford, G. A., Cline, A. L., Doscher, M., & Hoff, R. (2004). The reliability of 1- and 3RM tests of unilateral strength in trained and untrained men and women. *Journal of Sports Science and Medicine*, *3*(3), 190–196.
- McKay, B. R., De Lisio, M., Johnston, A. P. W., O'Reilly, C. E., Phillips, S. M., Tarnopolsky, M. A., & Parise, G. (2009). Association of interleukin-6 signalling with the muscle stem cell response following muscle-lengthening contractions in humans. *PLoS ONE*, *4*(6), e6027.
- Melibeu Bentes, C., Simão, R., Bunker, T., Rhea, M. R., Miranda, H., Matassoli Gomes, T., & da Silva Novaes, J. (2012). Acute effects of dropsets among different resistance training methods in upper body performance. *Journal of Human Kinetics*, *34*(1), 1–7.
- Mitchell, C. J., Churchward-Venne, T. A., Bellamy, L., Parise, G., Baker, S. K., & Phillips, S. M. (2013). Muscular and systemic correlates of

resistance traininginduced muscle hypertrophy. *PLoS ONE*, *8*(10), e78636.

- Moritani, T., & deVries, H. A. (1979). Neural factors versus hypertrophy in the time course of muscle strength gain. *American Journal of Physical Medicine*, *58*(3), 115– 130.
- Morton, R. W., Oikawa, S. Y., Wavell, C. G., Mazara, N., McGlory, C., & Quadrilatero, J. (2016). Neither load nor systemic hormones determine resistance trainingmediated hypertrophy or strength gains in resistance-trained young men. Journal of Applied Physiology, 121(1), 129–138.
- Morton, R.W., Sato, K., Gallaugher, M. P., Oikawa, S. Y.,McNicholas, P. D., & Fujita, S. (2018). Muscle androgen receptor content but not systemic hormones is associated with resistance training-induced skeletal muscle hypertrophy in healthy, young men. *Front. Physiol.*, *9*,1373.
- Murphy, C., & Koehler, K. (2020). Caloric restriction induces anabolic resistance to resistance exercise. *European J. Appl. Physiol.*, *120*,1155–64.
- Nascimento, M. A., Cyrino, E. S., & Nakamura, F. Y. (2007). Validation of the Brzycki equation for the estimation of 1-RM in the bench press. *Revista Brasileira De Medicina Do Esporte*, *13*(1), 40e–42e.
- Nieman, D. C., Davis, J. M., Brown, V. A., Henson, D. A., Dumke, C. L., & Utter, A. C. (2004). Influence of carbohydrate ingestion on immune changes after 2 h of intensive resistance training. *Journal of Applied Physiology*, *96*(4), 1292–1298.
- Oscarsson, J., Johannsson, G., Johansson, J. O., Lundberg, P. A., Lindstedt, G., & Bengtsson, B. A. (1997). Diurnal variation in serum insulin-like growth factor (IGF)I and IGF binding protein-3 concentrations during daily subcutaneous injections of recombinant human growth hormone in GH-deficient adults. *Clinical Endocrinology*, *46*(1), 63–68.
- Peake, J. M., Nosaka, K., Muthalib, M., & Suzuki, K. (2006). Systemic inflammatory responses to maximal versus submaximal lengthening contractions of the elbow flexors. *Exercise Immunology Review*, *12*, 72–85.
- Pearson, S. J., & Hussain, S. R. (2014). A review on the mechanisms of blood-flow restriction resistance training-induced muscle hypertrophy. *Sports Medicine*, *45*(2), 187–200.
- Pedersen, B. K., & Febbraio, M. A. (2008). Muscle as an endocrine organ: focus on muscle-derived interleukin-6. *Physiological Reviews*, *88*(4), 1379–1406.