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Donning a Novel Lower-Limb Restrictive Compression Garment During Training Augments Muscle Power and Strength

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ABSTRACT

International Journal of Exercise Science 13(3): 890-899, 2020. The popularity of graduated compression garments (GCG) in sport and exercise is largely driven by the abundance of anecdotal claims suggesting their efficacy. A new line of compression apparel, restrictive compression garments (RCG), integrate novel resistance technology into lower-limb compression garments designed to provide variable resistance to movement. This study aimed to investigate the effect of donning an RCG during a 4-week training program on selected performance variables. Twelve college-aged males were recruited for four weeks of lower-body strength-power resistance training. Participants were randomized 1:1 and blinded to (i) an intervention group (RCG; n = 6) that donned a lower-body RCG during training or (ii) a control group (SHAM; n = 6) that donned a sham during identical training. Both groups demonstrated significant increases in 1-repetition maximum (1-RM) on a seated leg press after 4 weeks (both $p < 0.001$), with RCG showing a significantly greater increase compared SHAM ($p = 0.005$, $g = 3.35$). Similarly, RCG demonstrated significantly greater increases in jump height, peak power, and average power compared to SHAM ($p = 0.032$, g = 3.44; $p < 0.001$, $g = 4.40$; $p < 0.001$, $g = 4.50$, respectively). Donning a RCG while engaging in lower-body strength-power training may augment increases 1-RM on a seated leg press, jump height, peak and average power, compared with same exercise training without an RCG.

KEY WORDS: Graduated compression garments (GCG), resistance training, jump performance

INTRODUCTION

The application of functional fitness-sport apparel innovations has been touted as having the ergogenic potential for improved performance and recovery from exercise. Graduated compression garments, for instance, have traditionally been prescribed clinically to promote positive hemodynamics, which helps to alleviate risk of clotting and edema when worn on the lower limbs (13). Although the majority of healthy individuals and athletes alike are at low risk for deep vein thrombosis or edema, a plethora of studies in the past decade have demonstrated that a multitude of additional mechanisms (*e.g.*, increased muscle oxygenation, skin temperatures, joint awareness and decreased muscle oscillations, perception of fatigue) are induced from donning graduated compression garments that may enhance exercise and sports performance as well as facilitate recovery (3, 4, 10, 19).

In contrast to the popularity of graduated compression garments in sports and exercise, a paucity of information exists regarding the potential ergogenic effects of a new line of proprietary compression garments, we refer to as 'Restrictive Compression Garments' (RCGs), on exercise training and sports performance. Recently, a novel RCG (Blueprint Phoenix; Redondo Beach, CA, USA) was developed that utilizes a compression pant designed with multiple layers of embedded elastic bands and panels that produce a patterned, internal resistance when stretched over the lower-body joints of the hip and knee. This engineering, in return, allows the RCG to impose a variable resistance on the anterior and posterior chains of the lower body musculature throughout their full range of motion (Figure 1).

Resistance training alone facilitates muscle strength by inducing both neurological activation, early on, and skeletal muscle (hypertrophic) adaptations (14) through traditional weightlifting, using resistance bands, weighted objects, and body weight movements. However, applying an additional, variable resistance to movements through a specifically designed compression garment—as RCGs are designed to—is a novel concept. Current research suggests that maximal gains in muscular hypertrophy are achieved through resistance training programs that maintain a moderate degree of muscle tension, and muscle fibers undergo the most growth when continuously stimulated (18). It is speculated that RCGs may accomplish this by providing a variable resistance to movement, forcing muscles to exert higher forces for all movements and requiring additional work and power output during resistance training. Moreover, most resistance training methods are vertical loaded, meaning that the resistance is gravity-based, which goes in only one plane of movement. Donning a RCG, however, may work in all planes while stretching and providing an additional progressive resistance regardless of gravity. While it is speculated donning an RCG may produce more strength and power than resistance training alone, this claim requires further scientific scrutiny.

To our knowledge, no published literature exists on the donning of RCG during an exercise training program, or the subsequent effects of the increased resistance on physical performance. Therefore, this study investigated the effects of this novel lower-body RCG on muscular power, strength, and endurance relative to a sham control garment in order to test the efficacy of added resistance in augmenting improvements in performance.

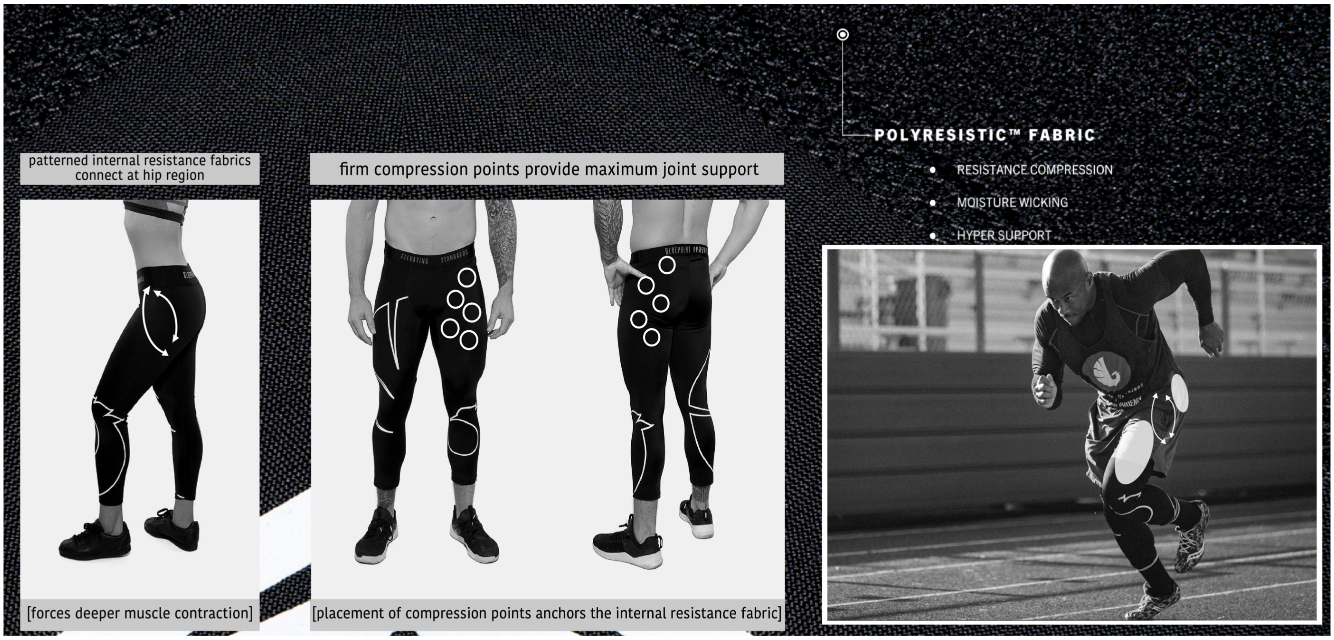

Figure 1. Illustrated RCG (Blueprint Phoenix; Redondo Beach, CA, USA) with compression pant designed with multiple layers of embedded elastic bands and panels that produce a patterned, internal resistance when stretched over the lower-body joints of the hip and knee.

METHODS

Participants

Twelve college-aged males were recruited from the University of California, Los Angeles (UCLA) campus through word of mouth and social media (i.e., Facebook and Twitter). Through self-report, participant criteria for study inclusion included resistance training with a minimum of 1 year, thrice-weekly workouts, while exclusion criteria included the presence of musculoskeletal, cardiovascular, pulmonary, metabolic, or other disorders that would preclude high-intensity exercise testing. The study was performed in accordance with the ethical standards of the Helsinki Declaration and was approved by the UCLA Institutional Review Board. All participants provided written informed consent.

Protocol

This was a prospective, double-blinded, randomized placebo-controlled study design. Participants were randomized 1:1 and blinded to (i) an intervention group (RCG; n = 6) that during training donned the lower-body RCG or (ii) a control sham group (SHAM; n = 6) that donned a lower-body RCG that was two sizes larger (but still snug to the body) with the inner elastic band removed. To guarantee investigator blinding, the provider of the intervention, data collector and data assessor were separate individuals that were masked from knowing those assigned to the intervention and sham groups. All participants engaged in a supervised, periodized, 1-month lower-body strength-power resistance training program in the Exercise Physiology Research Laboratory at UCLA. Supervised training sessions were thrice weekly (12 sessions total), and participants were asked to refrain from additional vigorous activity. At baseline, participants underwent (i) study familiarization (i.e., a 30 min video of the training program was observed), (ii) fitting and instructional usage of an RCG or 'sham' garment, and, also at post-testing, (iii) performance assessments of muscular strength, muscular endurance, and power (i.e., vertical jump height) as well as standard anthropometric measurements. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (15).

The four-week training provided to all randomized participants integrated portions of a previously validated, evidenced-based lower-body strength-power resistance training program that is effective for maximizing jump height and lower-body power output (8, 17). Table 1 describes the typical workout sequence and exercises performed in circuit totaling approximately 20 min, three times weekly for 4 weeks. A trained researcher, also blinded to the intervention and control, supervised each workout session individually and recorded workout data and compliance during each training session. The participants were encouraged to perform all exercises at maximal intensity with correct form throughout.

Table 1. Lower body strength-power resistance training program.

Warm-Up	Tempo/Timing
1. Forward and Back Leg Swing	- 20 Repetitions each, 1 circuit
2. Side to Side Leg Swing	- Performed at a comfortable tempo
3. Jog-in-Place w/ High Knees	
Circuit	**Tempo/Timing**
1. Squat Jumps w/ 15-25 lb vest	- Work-to-rest ratio, wk 1-2: 30 s work, 20 s rest
2. Split Lunges w/ 15-25 lb vest	- Work-to-rest ratio, wk 3-4: 40 s work, 20 s rest
3. Leg Press @ wt = 60-95% 1-RM	- 2 circuits with 3-minute rest period between circuits
4. Kettlebell Swings w/ 15-35 lb	- Performed at maximum effort
5. Plyometric Box Jumps w/ 15-35 lb vest	
6. Deadmill Sprints	
Cool Down	**Timing**
1. Hallway walk	- 2 minutes

To ensure accuracy, reliability and consistency in test administration, all pre-and post-testing occurred in the same laboratory and time of the day (*i.e.*, early evening to optimize diurnal effect on strength) by the same investigator. Based on energy system requirements and the skill demand of the tests, the following sequence was followed (14):

1. Anthropometrics: Height was determined using a precision stadiometer (Seca, Hanover, MD). Body mass and percentage body fat (BF%) was measured using a validated (6) octipolar, multi-frequency, multi-segmental bioelectrical impedance device (270; InBody Co., Seoul, South Korea). Since hydration state has a marked influence on bioelectrical impedance analysis (BIA) results, participants were instructed to remain hydrated and avoid caffeine and heavy exercise during the 12-hour period before testing. Data were collected after at least three hours of fasting and voiding.

2. Muscle strength and endurance: Lower-body isotonic muscle strength was measured by determining 1-repetition maximum (1-RM) on a seated leg press (Eagle NX; Cybex International, Medway, MA) using the procedure described by the National Strength and Conditioning Association (1). The 1-RM is defined as the highest weight lifted through one full range of motion at maximal effort. Briefly, subjects performed a light warm-up including whole body exercise on a treadmill or cycle ergometer, followed by light stretching. They were then positioned on the leg press machine with their backs remaining flat against the seat back. The seat position was adjusted so that there was 90 degrees of knee flexion with the soles of the shoes flat on the foot plate. Individuals' seat positions were recorded for use in post-testing. Participants were allowed several practice trials of each exercise with minimum resistance to ensure good form, full range of motion, and good breathing technique. The resistance was progressively increased by trained researchers following standard procedure, leading to an attempt to complete 1–2 repetitions at a load estimated to be near maximum. Subsequently, the participant rested for 2 minutes and then attempted to achieve the 1-RM. For each 1-RM trial, participants attempted 2 repetitions. If participants were able to complete 2 repetitions, they were given a 2-minute rest and the load was increased. If participants failed the 1-RM attempt at the given weight, 2-minute rest was provided, and the load was decreased to the midpoint between the last successful lift and the failed lift. The 1-RM is defined as the highest weight lifted through a full range of motion 1 time only. After ten minutes of rest, muscle endurance was measured as the number of repetitions to failure using 85% of 1-RM values.

3. Lower-body average and peak power: Leg power was estimated using a previously validated (12) electronic jump mat (Just Jump; Probotics, Inc., Huntsville, AL, USA). To minimize the effects of fatigue from the strength and endurance test, a 30 minute rest period was implemented prior to this testing. Participants stood on the mat with feet at hip width and then performed a countermovement jump for maximal height. Jump height was recorded with a handheld computer interfaced with the jump mat. Three trials were given with 30-second rest between trials. The best trial was used to calculate peak and average leg power using published equations that required jump height and the subject's body mass (9). Jump height (Ht) was determined from "hang time" defined as time (s) from the feet leaving the mat to their return and the following equation: $Ht = t^2 \times 1.227$, where t is hang time in seconds and 1.227 is a constant derived from the acceleration of gravity.

Statistical Analysis

Descriptive statistics are presented as mean ± standard deviation (SD). Statistical significance was determined based on $\alpha = 0.05$ and all tests were two-tailed. Continuous variables were first assessed for normality via Shapiro-Wilk tests. Within-group comparisons at baseline and after 4 weeks were made by paired *t*-tests and Wilcoxon signed-rank tests for normally and non-normally distributed variables respectively. Changes between groups after one month of training were made by Welch's *t*-tests if data were normally distributed and Wilcoxon rank-sum tests if data deviated significantly from normality. A Holm-Bonferroni correction to control the familywise error rate was applied. Effect sizes were measured by Hedges' *g*. Analysis was performed in Excel (Microsoft Corporation, Redmond, Washington) and R (version 3.5.1; R Foundation for Statistical Computing, Vienna, Austria). Due to a dearth of previous literature reporting data regarding RCGs and performance variables, it was not feasible to conduct an accurate pre-hoc power analysis to determine sample size. Therefore, it is advised that the results of the present investigation be interpreted as pilot data.

RESULTS

All twelve participants successfully completed the 4-week training program with no missed sessions. Selected performance measures were collected at both baseline, and after 1 month, for all subjects (Table 2). No significant change in body mass or body fat percentage was detected within either group or between groups. In contrast, both groups demonstrated significant increases in 1-RM on a seated leg press after 4 weeks (both $p < 0.001$), with the RCG group showing a significantly greater increase compared to the SHAM group ($p = 0.005$, $g = 3.35$). Additionally, only the RCG group exhibited a significant increase in 85% of 1-RM ($P = 0.015$) yet it did not significantly differ from the improvement observed in the SHAM group. Both groups showed significant increases in jump height (both $p < 0.001$), peak power ($p = 0.002$ and $p < 0.001$ for the SHAM and RCG groups respectively), and average power ($p = 0.001$ and $p < 0.001$). For all three of these outcome variables, the RCG group demonstrated significantly greater increases compared to the SHAM group ($p = 0.032$, g = 3.44; $p < 0.001$, $g = 4.40$; $p < 0.001$, $g = 4.50$ for jump height, peak power, and average power respectively).

Table 2. Outcome variables at baseline and after 4 weeks for all participants.

	Groups (*n* = 6)	Baseline	1 Month	Change	P-within†	P-between†	Hedges g
Age	C	21.50 ± 1.0	-	-	-		
(yr)	I	19.80 ± 0.8	-	-	-	-	-
Height	C	178.2 ± 3.7	-	-	-		
(cm)	I	178.2 ± 9.6	-	-	-	-	-
Body Mass	C	82.2 ± 3.7	82.2 ± 3.4	00.0 ± 0.5	1.000		
(kg)	I	75.1 ± 5.5	75.3 ± 5.0	0.20 ± 0.7	1.000	1.000	0.33
Body fat	C	8.70 ± 3.1	8.70 ± 2.9	-0.10 ± 0.3	1.000		
(%)	I	12.7 ± 5.2	12.6 ± 4.8	-0.10 ± 0.5	1.000	1.000	0.00
1-RM	C	176.1 ± 29.5	193.2 ± 30.7	17.00 ± 2.40	< 0.001***		
(kg)	I	172.0 ± 29.1	209.8 ± 33.9	37.90 ± 8.5	< 0.001***	0.005**	3.35
85% pf 1-RM	C	10.2 ± 2.6	11.8 ± 2.8	1.70 ± 1.5	0.126		
(reps)	I	11.5 ± 3.3	15.5 ± 1.5	4.00 ± 2.1	0.015*	0.162	1.26
Jump height	C	60.3 ± 9.4	70.4 ± 9.7	10.1 ± 2.2	< 0.001***		
(cm)	I	54.2 ± 5.5	72.4 ± 4.5	18.2 ± 2.5	< 0.001***	0.032*	3.44
Peak power	C	5665.5 ± 866.4	6421.8 ± 827.5	756.3 ± 237.6	0.002**		
(W)	I	4756.0 ± 499.5	6398.1 ± 412.2	1642.1 ± 157.1	< 0.001***	< 0.001***	4.40
Average power	C	2768.2 ± 454.8	3167.3 ± 416.4	399.1 ± 165.2	0.001**		
(W)	I	2267.8 ± 248.1	3290.3 ± 178.4	1022.5 ± 105.2	< 0.001***	< 0.001***	4.50

Values are mean ± SD. No significant differences were observed at baseline between groups. 1-RM = one repetition maximum; C = Control; I = Intervention; †after correcting for multiple comparisons; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

DISCUSSION

The aim of this study was to investigate the effects of donning RCGs during training on performance measures as compared to a sham garment. We found that individuals donning RCGs during exercise experienced greater improvements in lower limb peak and average power output, muscular strength, and jump height than those donning shams. Given that there is a lack of previous research investigating RCGs in combination with resistance training in current literature, we believe this study is the first to indicate that donning an RCG during training augments improvements in performance measures. As RCGs are intended to provide resistance that previous GCGs have not, this novel technology could be a promising training tool for athletes and fitness enthusiasts alike.

Both study research arms underwent identical training programs in order to directly assess the potential improvements in performance associated with donning the RCG. These garments are designed to increase resistance during periods of exercise, and rates of recovery following it, so uniform regimens ensured that RCGs were responsible for the differences in performance outcomes between groups. Past studies indicated that strength-power training is more effective than other targeted training in producing all-around improvements in the load-power, load-force, and load-velocity relationships of the legs, all of which indicate its superior transference to a wide variety of on-field demands associated with strength–power sports (5). In order to induce maximal changes in lower-limb strength and power among all participants, a nonlinear, periodized strength-power program was implemented (Table 1). As both groups demonstrated increased 1-RM on a seated leg press, jump height, average and peak power following the 4-week training period (Table 2), the increased improvements observed across the intervention group relative to the control group could be directly attributed to the proprietary restrictive components (i.e., elastic overload) of the RCGs.

The literature is mostly void of other functional fitness-sport type apparel augmenting performance from training; only two previous studies investigated the effects of donning traditional graduated compression garments (GCG) on individuals during plyometric and sprinting exercises. A study by Born et al (3), comparing voluntary performance and recovery effects of donning GCGs during a controlled period of sprint-based exercise, found GCGs had no difference and minimal effect size on voluntary performance measures including 20-m sprint measures and bounding performance. Furthermore, recent comprehensive measurement of the utility of GCGs in augmenting performance measures concluded that compression garments may improve athletic performance, yet only with considerably low magnitude (7).

It is well established that lower-body plyometric training enhances power via the stretch-shortening cycle (SSC) by increasing the stretch-load of active muscles while generating enhanced propulsive forces (11). Donning an RCG may provide additional resistive properties (*i.e.*, elastic overload) to the SSC matrix, hence theoretically enhancing the stretch-load of active muscles and providing greater propulsive forces in terms of vertical jumps. Moreover, there is a significant positive relationship between hip extensor work and vertical jump height, as a previous research has indicated that 75% of the variance in isokinetic torques (peak work capacity of muscle) measured among subjects was represented by individuals' jump height (16). RCG garments are designed such that multiple panels support the internal resistive fibers, which concentrates the force of resistance at the panel. During some lower-limb movements, internal fibers provide resistance as a result concentrating pressure at the hip flexors across one's entire range of leg movement from varying directions during the strength-power circuit intervention. Given that the effects of donning an RCG are concentrated at these muscles, the connection between hip extensors and jump height suggest wearing these garments plausibly accounted for the significant difference in jump height, as well as 1-RM, peak power, and average power between the intervention and control groups.

A limitation of the findings in the present investigation is the effect that wearing a tight-fitting pant may increase proprioception. Compression garments have been shown to: (*i*) enhance proprioception as a result of changes in sensory feedback transmission through mechanoreceptor activation and thus, (*ii*) improve accuracy, precision, and sensitivity around the joint where it is applied by serving as a filter for tonic mechanoreceptor signaling (2). Moreover, another recognized limitation of our study was the lack of individualized garment sizing. Like most garments, the RCG does not account for inter-subject variability in lower body size and shape which could alter the level of compression and resistance afforded by the garment. Although statistical power was calculated in advance, it is also important to acknowledge the small sample sizes may have increased the risk for both type 1 and type 2 errors. This is partially ameliorated by careful selection of outcome measures and interpretation of results based on the pattern of findings in each domain; however, future larger studies are recommended to confirm our results.

This study also had several strengths. The participants had similar demographics and similar exercise training history suggesting that baseline fitness would be equivalent between groups and the "window for improvement" would be similar. Another clear strength included a control sham group utilizing an identical RGC albeit 2x larger and without resistive bands, which was undetectable by the users (i.e., all indicated this in a post-study survey). Finally, a major feature and strength of this study was the application of current evidence-based recommendations that suggest the superiority of a 4-week, nonlinear (e.g., undulating) periodized strength-power resistance training scheme in maximizing strength, endurance and power. This training scheme was selected due to past literature indicating that subjects who underwent a nonlinearized-training scheme incurred increases in absolute strength in leg press roughly twice that of subjects simultaneously performing a linearized-training scheme, across measurements at 4, 8 and 12 weeks (17). As our study aimed to identify whether donning RCGs during training improved performance measures specific to lower-limb strength and power, and given the paucity of literature suggesting nonlinear periodization incurs superior strength gains (8), this general scheme of training was followed.

In sum, this study demonstrates that lower-body strength-power training augmented with a novel RCG in recreationally trained young men may optimize increases in performance outcomes such as 1-RM, jump height, peak power, and average power, compared with same exercise training without an RCG augment. Future investigations should explore the reproducibility and utility of these results in other populations such as females, athletes, those afflicted with lifestyle diseases, or those recovering from injury through physical therapy.

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