Original Research

Three Week Hypergravity Training Intervention Decreases Ground Contact Time During Repeated Jumping and Improves Sprinting and Shuttle Running Performance

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ABSTRACT

International Journal of Exercise Science 9(2): 149-158, 2016. This study examined the effects of a non-traditional training method, hypergravity training (HT), on anaerobic performance. Highly active men (n = 9) completed a 3 week HT protocol in which weighted vests were worn 8 h/day, 4+ days/week separate from training. Vest loads were 11.2 ± 0.6% of body mass during week one, and increased to 13.2 ± 0.7% (week 2), and 16.1 ± 0.4% (week 3). Performance testing included power clean 1-RM (PC), counter movement jumps, 4 continuous jumps, 36.6 m sprints (SP), a 137.2 m short shuttle run (SSR), and a 274.3 m long shuttle run (LSR). A 3 week non-hypergravity training period (NHT) proceeded HT. Baseline SP improved from 4.69 ± 0.29 s to 4.58 ± 0.22 s post-treatment, and regressed after NHT (4.69 ± 0.24 s) ($p = 0.006$, ES = 1.80). Improvements in SSR ($p = 0.012$, ES = 1.71) occurred from baseline (26.7 ± 1.5 s) to post-treatment (26.2 ± 1.4 s), followed by a return to near-baseline values (26.9 ± 1.8 s). Jumping tasks displayed similar trends, but no statistical differences and modest effect sizes (0.51 - 0.62) were found except for improved ground contact time during repeated jumps post-HT (ES = 2.26). PC and LSR performances did not improve. Three weeks of HT significantly enhanced short running task performances and decreased ground contact time between 4 continuous jumps. HT may be incorporated into training programs prior to key points in an athletic season without hindering the quality of regular training session activities.

KEY WORDS: External load, load carriage, sprint, weighted vest, ground contact time

INTRODUCTION

Hypergravity training (HT) consists of wearing a weighted vest (WV) during daily activities for a 3 - 4 week period. Bosco and colleagues (3,4,5) proposed HT in addition to wearing a WV during training could result in anaerobic performance increases in well-trained athletes through neural and myogenic adaptations such as the number and/or frequency of muscle fiber motor unit activation and improved ATP resynthesis. The investigators' theory was supported in their seminal study (5), as HT coupled with wearing a WV during training improved explosive jumping power characteristics in a small group (n = 6) of internationally competitive jumpers and throwers. The HT period lasted 3 weeks and improved single vertical jump (VJ) height, drop jump height, and mean power output during a set of 5 continuous jumps; while no change in performance was exhibited for these tasks in a control group (n = 5). Further strengthening the effect of HT was noted as 4 weeks of removal of the WV resulted in a return to baseline performance for the treatment group.

Bosco and colleagues completed two other comparable HT studies in the early 1980's (3,4) and found similar results concerning power improvement with small samples of elite male and female national level athletes. Only two additional investigations have been published since. Sands et al. (18) found similar improvement trends in jumping tasks when 3 weeks of HT was incorporated into a training program for collegiate female track athletes. A recently published study (2) found that shorter HT intervention (8 days) did not improve sprint performance but reduced ground contact time during sprinting in elite rugby players.

Wearing a WV during training is a popular trend among individuals seeking performance improvements, but the efficacy of this practice remains somewhat in question (15). In contrast, nearly all studies to our knowledge that have examined HT in trained populations (3, 4, 5, 17, 18) have found positive results concerning anaerobic performance tasks. However, the populations examined (predominantly elite level athletes) and performance tasks (mostly jumping task) used in previous HT investigations have been limited in scope and have often incorporated a between subjects design with small sample sizes. The effects of HT are also somewhat unclear as every published study has included wearing a WV during both daily living and training activities. Proper periodization allows athletes to peak in performance during the most important part of the competitive season, and the addition of HT during daily living activities only may optimize competition performance without interfering with the quality of individual workouts. Therefore, the purpose of this study was to determine the effects of a ~21 day HT protocol on multiple types of anaerobic task performances in well-trained young men.

METHODS

Participants

Investigators recruited highly active male fitness athletes (n = 9) with a minimum of 12 months experience (4 sessions per week) from local CrossFit gyms. All participants competed in fitness competitions at levels ranging from local to regional. Eleven participants were initially recruited, but two were unable to complete all testing sessions due to injury unrelated to the study or schedule conflicts. A priori power analysis determined that a sample size of 8 would be needed if the change in percentage of performance between treatments was 3 ± 1.5%, with an alpha of 0.05 and power set at 0.80. Prior to data collection, participants completed and signed a written informed consent form that outlined the requirements and risks of the study. Age (21 ± 2 years), mass (91.1 ±

4.4 kg) and height (181 ± 1 cm) were recorded prior to testing. Height and mass were measured using a digital scale (Tanita EWB-800, Tokyo, Japan) and a standard stadiometer respectively. Body fat percentage (11.2 ± 3.9 %) was estimated using Lange skinfold calipers (Cambridge, MD, USA) and a 3-site method (men: chest, abdomen, thigh) (16). All procedures were approved by the local Human Subjects Committee.

Protocol

Following anthropometric data collection, all participants completed the first of two familiarization session (protocol described below). During the first familiarization trial participants were instructed on how to complete each performance tasks and then allowed to practice the tasks as many times as desired. Approximately one week later, participants returned to complete a second and final familiarization session. During this session, the order of performance tests and rest periods were identical to that used during the experimental trials.

A week later, participants completed a pre-experimental baseline test for the HT intervention. Three weeks after HT intervention, a post-HT trial was completed. This trial also served as the baseline performance testing for the three week non-hypergravity training period (NHT). During NHT participants continued training as normal, but did not wear a WV during daily living. Participants were restricted from alcohol, excessive caffeine consumption, and working out the day before testing. Participants were not allowed to complete exhausting workouts 2 days prior to testing. Differences in exercise regimens were not accounted for, but activity logs were implemented and assessed to assure that drastic differences in training type or volume did not occur between treatments. Although participants were recruited from multiple gyms, most participants often completed the same standardized workout of the day provided by the CrossFit headquarters' website.

Tests were divided into two phases. The current manuscript reports the first half of the tasks that were conducted without a WV. The second sets of tasks were designed to simulate tactical athlete specific tests (e.g. stair climbing and casualty drag) and were conducted while wearing a WV (Lowe et al. In review). These tasks were performed last and did not interfere with the tasks discussed in the current manuscript.

Participants performed a 10 min self-selected warm up prior to completing a power clean 1-RM protocol. All participants were familiar with the lift and were given 3 attempts to find their 1-RM. It was assumed that the two familiarization sessions would allow for an accurate estimation of 1-RM during the baseline session.

The next tests included two types of vertical jumping tasks. The first was a standard counter-movement jump test. Participants completed a set of 3 single countermovement jumps (CMJ1) with 60 s rest between reps. Results were analyzed based on cumulative average of all jumps. The second vertical jump test consisted of 2 sets of 4 continuous jumps (CMJ4). The CMJ4 sets were separated by 60 s rest periods, and the average jump height and ground contact time between jumps were used for statistical analyses. A contact time mat (Just Jump, Probotics, Huntsville, AL) was used to determine maximal jump height during the CMJ1, and to report the average jump height and contact time between jumps for the CMJ4 test.

Following jump performance testing and a 4 min rest period, 3 sprints (SP) were conducted on a rubber-padded concrete gym floor. Participants started from a 2-point stance and time was recorded from 4.57 - 41.15 m (5 – 45 yd) to reduce start mechanics variability. Photogate timing devices (Brower Timing Systems, Draper, UT, USA) accurate to the nearest hundredth of a second were used. After sprint testing, participants completed 2 shuttle runs. The first was 6 x 22.86 m (SSR) and the second was 12 × 22.86 m (LSR). Both were completed with all participants running simultaneously in a competitive fashion and were timed individually by assigned investigators using stopwatches. A three and a half minute rest period separated each different task including rest time between shuttle running bouts. Procedures for all subsequent tests were performed in identical fashion. Performance tests were chosen to include high intensity tasks of multiple durations ranging from single maximal efforts (PC & CMJ1) to repeated efforts lasting ~ 3-6 s (CMJ4 & SP), 25-30 s (SSR), and 60 s (LSR).

Each participant was fitted with a WV (ZFO Sports, San Jose, CA, USA) that was worn 4 or more days per week and for ≥8 h a day on the days the vest was worn. To reach the ≥8 hour requirement, participants could wear the WV in periods broken up throughout the day, or for ≥8 hours continuously. Participant's weight vests were loaded according to a predetermined percentage of the individual's body mass. The mean initial load was 11.2 ± 0.6 % of the participant's body mass for the first week. The load was increased to 13.2 ± 0.7% the second week, and to 16.1 ± 0.4 % for the third week. The HT phase lasted ~21 days followed by 21 days of NHT. Each day the WV was worn, participants reported the hours worn, physical activities performed, and discomforts from wearing the vest in a daily activity log. Investigators communicated with each athlete daily via text message to ensure protocol compliance and remind participants to record their training activities.

Statistical Analysis

Changes in pre-post performance were compared between HT and NHT phases for each performance tasks using dependent samples t-tests. All data are represented as means and SD and displayed in absolute values or Δ pre-post percentage (Δ% = treatment - baseline / baseline). Cohen's D effect size data was also calculated by dividing the raw difference of the change in weight lifted, jump height, ground contact time, or time to complete a running task between treatments divided by pooled SD of both training phases. One participant's data was excluded for PC because of a minor wrist injury unrelated to the study, and one participant's CMJ4 data was excluded because they had a difficult time landing on the mat consistently resulting in high inter-trial variability. Statistical significance was considered when $p \leq 0.05$.

RESULTS

All participants wore the WV for a minimum of 32 h per week each week and averaged 34 ± 4 h per week throughout the

Table 1. Descriptive data for performance testing variables (n = 9; mean ± SD).

Variable	Baseline	HT	NHT	Δ BL to HT		Δ HT to NHT			
				Absolute	%	Absolute	%	p	ES
PC (kg)*	125.0 ± 16.6	125.9 ± 17.9	125.0 ± 17.5	0.9 ± 4.9	0.5 ± 3.8	-0.9 ± 5.7	-0.8 ± 4.7	0.390	0.34
CMJ1 (cm)	70.9 ± 9.4	72.1 ± 9.7	71.9 ± 8.9	1.3 ± 2.4	1.9 ± 3.5	-0.3 ± 3.8	-0.2 ± 5.3	0.330	0.51
CMJ4 (cm)*	64.0 ± 9.1	64.5 ± 7.9	63.0 ± 6.9	0.6 ± 3.2	1.2 ± 4.9	-1.5 ± 3.6	-2.1 ± 5.5	0.280	0.62
GCT (s)*	0.37 ± 0.10	0.34 ± 0.07	0.36 ± 0.07	-0.04 ± 0.03	-5.98 ± 8.69	0.02 ± 0.02	6.62 ± 7.44	0.001	2.26
SP (s)	4.69 ± 0.29	4.58 ± 0.22	4.69 ± 0.24	-0.72 ± 0.09	-1.48 ± 1.99	0.11 ± 0.11	2.40 ± 2.40	0.006	1.80
SSR (s)	26.7 ± 1.5	26.2 ± 1.4	26.9 ± 1.8	-0.3 ± 0.6	-1.0 ± 2.1	0.7 ± 0.6	2.6 ± 2.0	0.012	1.71
LSR (s)	60.4 ± 4.1	60.1 ± 3.0	60.1 ± 4.4	-0.4 ± 1.6	-0.5 ± 2.7	0.1 ± 2.4	0.1 ± 3.8	0.704	0.23

Power clean (PC); Single counter movement jump (CMJ1); Four continuous counter movement jumps (CMJ4); 36.58 m sprint (SP); 137.16 m shuttle run (SSR); 274.32 m shuttle run (LSR); Ground contact time (GCT) during the CMJ4. (* indicates n = 8).

HT period. Participants trained heavily and averaged very similar numbers of sessions for resistance training (HT = 4.6 ± 1.2; NHT = 4.4 ± 1.7 days per week), sprint and jump training (HT = 0.9 ± 0.7; NHT = 0.7 ± 0.8 days per week), and endurance training (HT = 1.8 ± 1.7; NHT = 1.3 ± 1.3 days per week). Participants averaged completing 3.0 ± 1.0 and 2.5 ± 1.8 standardized workouts per week during NHT and HT respectively.

Raw data from baseline, post-HT, post-NHT, and change in performance for each treatment expressed in absolute values and by percentage are displayed in Table 1. Effect sizes for change in absolute values for HT versus NHT are also displayed in Table 1. Significant improvements in GCT, SP, and SSR performance occurred after the three week HT phase, followed by a return to near baseline values after NHT (Table 1). Figures 1 and 2 display individual changes in performance for mean SP and SSR across baseline, HT, and NHT phases. Individual changes in mean ground contact time during repetitive jumping (CMJ4) from baseline, HT, and NHT performance testing are displayed in Figure 3.

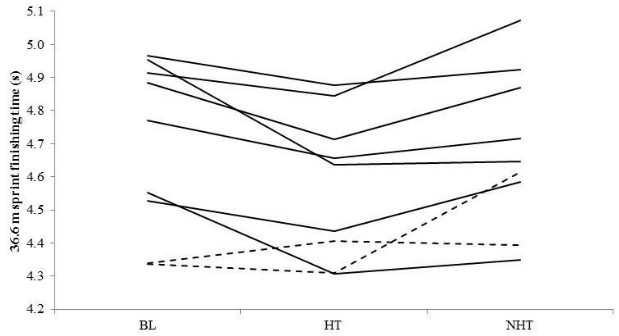

Figure 1. Individual mean times for 3 sets of 36.6 m sprints at baseline, HT, and NHT. Dashed lines represent individuals that did not improve from baseline to HT.

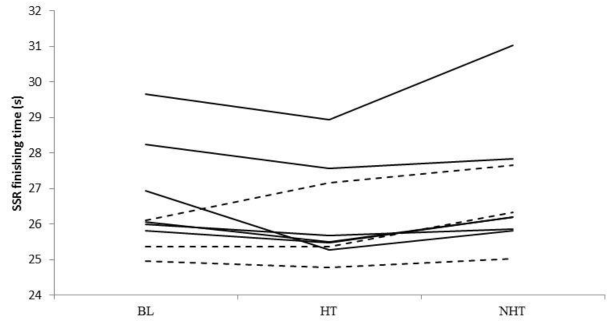

Figure 2. Individual 137.2 m shuttle run times at baseline, HT, and NHT. Dashed lines represent individuals that did not improve from baseline to HT.

DISCUSSION

HT has been proposed as an unconventional method to improve anaerobic task performance. Prior investigations have determined single and multiple vertical jumping task performance

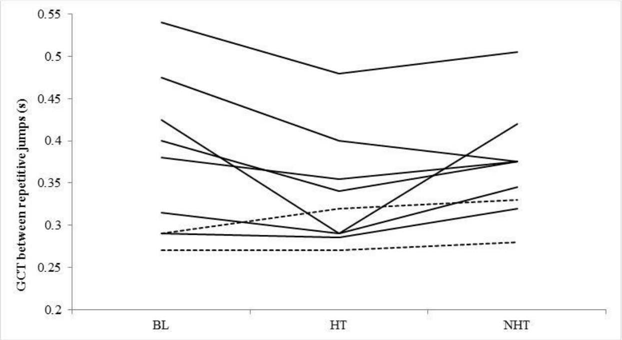

Figure 3. Individual GCT during repetitive jumping (CMJ4) at baseline, HT, and NHT. Dashed lines represent individuals that did not improve from baseline to HT.

is vastly enhanced following HT coupled with wearing a WV during training sessions for collegiate and international level sprinters and jumpers (3, 4, 5, 18), but the only study assessing sprinting found a single week of HT did not improve performance (2). The current study was unique in that it allowed for isolated observation of HT without external loading during training and provided additional evaluation of changes in running task performances after longer HT exposure in well-trained but non-elite young men.

Most previous HT studies have noted significant improvement in jumping task ability with mean improvements in vertical jump height reaching 10.6 cm after 3 weeks of HT (3, 4, 5, 18). Despite modest improvement in average peak jump height for both CMJ1 and CMJ4 during HT phases versus decreases in both tasks during NHT (Table 1), no statistically significant improvements were observed in jumping height. However, ground contact time between each jump during CMJ4 decreased significantly after the HT period, and returned to near baseline values after NHT.

The increased focus on jump training in the populations previously studied possibly explain why a lesser impact was noted in our participants. Bosco (3) specifically recruited participants who were competing at the international level in track and field and failed to increase jump height even after a year of rigorous training with a large emphasis devoted to jumping and plyometric drills. Other HT study samples included participants of similar skill level and training protocols focused on improving jump height and mechanics (5, 18). Although the participants in the current study were highly fit and regularly trained, their jump heights would not be comparable to elite male sprinters or jumpers and much of their jumping tasks likely occurred under more of a conditioning context than skill improvement paradigm (e.g. large volumes of repeated box jumps). Despite no statistical improvement in CMJ1, the significantly shorter CMJ4 ground contact time and mean improvements of greater than 2% for both CMJ1 and CMJ4 height followed by a decline in performance after cessation of HT support that the more reasonable HT protocol incorporated in the current study provided a sufficient stimulus to induce physiological adaptations and resulted in a practical real world performance difference for many of the athletes in regards to jumping performance.

It must also be considered that with the exception of Sands et al. (18), who stopped using WV during training because of lower leg injuries and Barr et al. (2), all other HT and WV studies have required participants to wear a WV during training. Data is limited, but similar results supporting a greater efficacy of WV training in elite versus non-elite athletes are exhibited in studies that have incorporated WV during training only. Professional basketball players who wore WV during plyometric training improved in multiple types of jumping tasks versus controls, but studies that have required wearing WV during training only in recreationally trained individuals have failed to show greater improvement in jump performance versus individuals who completed jump training without an external load (14) or failed to result in any improvements (20). More research is needed, but results indicate such training could benefit less elite athletes in sports that require vertical jumping such as basketball or volleyball.

Prior research has indicated a strong correlation between power output produced by male athletes during maximal vertical jumping and Olympic lifting ability (snatch, r = 0.93; clean and jerk, r = 0.90) in experienced weightlifters (6). Supporting this association, as with CMJ1 and CMJ4, no statistical differences were noted in PC 1-RM change between HT and NHT phases. The consistency in means (Table 1) is masked by high inter-individual variability in performance. Four of the participants had greater improvement during HT and 3 participants had greater performance improvement during NHT. Although the participants regularly incorporated Olympic style lifting in their training (HT = 3.4 ± 0.9; NHT = 2.8 ± 1.3 days per week) and displayed respectable 1-RMs, it is plausible that the diversity of results is attributable to less proficient technique versus athletes who compete in Olympic lifting or increments in which intensity was increased (i.e. 2.28 kg after each successful lift) was not sensitive enough to detect as subtle performance improvement as noted in other tasks. Past studies indicate that highly skilled athletes near their maximum potential at a particular task such as jumping (3, 4, 5, 18) are more likely to benefit from HT or wearing a weight vest during the specific task during training (11). Future HT studies with athletes who compete in and have prolonged training experience in Olympic lifting may find different outcomes.

There is a popular anecdotal acceptance that external load sprint training benefits unloaded sprinting. Cronin et al. (9) proposed that sprint training while wearing a WV increases eccentric strength of the leg extensor muscles and musculotendonous stiffness, consequently improving the acceleration phase of sprinting tasks; however, we are unaware of any training studies that support this concept. The addition of external load during training does not improve sprint and shuttle run times compared to unresisted training protocols, and running while wearing a WV decreases step length, stride rate, and flight time, while increasing ground contact time at maximal velocity (8, 10, 19, 20). It is plausible, that athletes may retain the slower kinematic running pattern induced by running with an external load over the course of several weeks resulting in sprint performance decrement (7).

While HT failed to yield statistically significant increases in jumping task performance, results indicate that HT was an effective training aid for improving sprint and shorter shuttle run performance. Running performance displayed significant improvement ($P < 0.01$) in both SP and SSR during HT vs. NHT and produced large effect sizes, but no significant changes were noted in the LSR (Table 1). Figures 1 and 2 display individual changes in percentage of performance for SP and SSR, respectively. All but 1 and 2 participants improved in SP and SSR from baseline to HT, respectively. Further strengthening this observation, all individuals in SSR and all but 1 individual in SP decreased in performance at the end of NHT versus post-HT even though NHT took place during weeks 3 through 6 weeks resulting in 3 additional weeks of training time.

Despite promising results in pilot tests and reduced ground contact time, Barr et al. (2) found no improvement in first 10 or last 10 m velocity during 40 m sprinting in elite rugby players. The authors suggested the short intervention period used and that the rugby players' pre-season high volume of conditioning may have negated the influence of HT. Lowe et al. (In review) (13) reported immense changes (ES = 1.9 - 2.6) in horizontal running tasks including a short sprint that required participants to change direction 3 times and kneel behind objects of cover twice, backwards running while dragging a 84.9 kg sled, and 182.9 m shuttle run while wearing a 12 kg WV. However, less dramatic improvement was noted during stair ascension sprints by Lowe et al. (In review) (13) (5 flight stair climb: p = 0.03; ES = 1.05; split for first 3 flights: p = 0.13; ES = 0.68). The discrepancies between improvements in vertical vs. horizontal focused movement tasks in both studies are intriguing.

In addition to negative alterations in running kinematics, recent revelations have determined that sprinting with a WV does not result in increased vertical ground reaction forces versus unweighted sprinting due to the smaller rise in center of gravity during sprinting flight phases conducted while wearing a WV (8, 10). Perhaps, the potential negative motor learning and movement pattern residual effects that are associated with WV sprint training are not transferred during HT, but the neuromuscular adaptations that have been credited with the effectiveness of HT are still incurred when the WV is worn during daily living alone. The largest ES for any measured variables was exhibited for ground contact time during the CMJ4, but total power (i.e. jump height) during both jumping task did not differ to as great of an extent as running performance improved in SP and SSR. HT without wearing a WV during training may have resulted in decreased time for neural activation of Type II muscle fibers but failed to increase peak power output as significantly. This theory may help explain why SP and SSR improved but PC and jumping tasks did not. Both running tasks required repetitive ground contacts and/or change in direction. Improvement in rate of muscular recruitment could have resulted in multiple steps in which foot-ground contact time was decreased. Enhanced vertical vector force production may require external loaded jump training and explain why Khlifa et al. (11) found significant improvement for basketball players completing plyometrics with WV, while sprinting with a WV does not improve sprinting (7, 19, 20). Regardless of the mechanism, the immense improvements in SP and SSR times in addition to findings by Lowe et al. (unpublished data) (13) suggest that HT may be a more effective training aid in comparison to training while wearing a WV for enhancement of sprint agility tasks lasting 4 - 40 s.

The major limitation of the current study was that participants did not follow a standardized training protocol and nutritional factors such as diet and supplements were not controlled. Although physical activity was self-selected, participants completed very similar training routines during each treatment phase and completed many of the same CrossFit 'workouts of the day' which are standardized across gyms. Additionally, direct evidence regarding physiological mechanisms that resulted in the enhancement of SP, SSR and ground contact time during the CMJ4 is lacking. Because of concerns for impairment during space flight, the effects of extended exposure to hypogravity have been examined in depth. Chronic exposure to microgravity or limb unloading results in significant skeletal muscle atrophy (21) and even greater decreases in maximal skeletal muscle explosive power, particularly in the lower limbs (1, 12). The effects of chronic skeletal muscle loading has not been as widely investigated and as with the current investigation, most studies have focused on performance outcomes versus mechanistic explanations for alterations in performance improvement. However, it could be speculated through the consistency of opposing outcomes within hypogravity versus hypergravity studies that HT results in reverse muscular and neurological adaptation pathways from reduced chronic skeletal muscle loading. Future research is warranted to determine if performance improvements from HT are attributed to neurological, fiber typing, or metabolic adaptations that have been previously proposed (3, 4, 5). Additional work needs to be completed to determine optimal HT duration and loading schemes.

The application of HT appears to be an effective training aid for the enhancement of short distance sprinting and shuttle running and decreases ground contact time during repeated jumping. The addition of external load during jumping activities might be required if jump height improvement is the primary training objective. For optimal periodization, athletes should consider incorporating HT during the 3 weeks leading up to post-season competition or key games as the effects of HT are transient. Wearing the WV for 32 h per week produced significant improvements for the sample, but the participant who accumulated the most hours wearing the WV improved the most in SP and SSR suggesting additional exposure to HT may result in greater change in performance. While HT was successful in improving multiple anaerobic performance tasks, physical discomfort was experienced by several participants in the erector spinae and trapezius muscles, and on the shoulders at the points of contact with the WV during HT. Almost all of the reports of discomfort occurred during the first days of wearing the vest and waned within 2-3 days. This should be taken into consideration and a progression beginning with lighter loads and a "practice" HT period should probably take place before the competitive season commences.

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