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Effects of a Climbing-Specific Training Program on Upper-Body Power in Novice Climbers Compared to Advanced Climbers

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EFFECTS OF A CLIMBING-SPECIFIC TRAINING PROGRAM ON UPPER-BODY POWER

IN NOVICE CLIMBERS COMPARED TO ADVANCED CLIMBERS

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ABSTRACT

EFFECTS OF A CLIMBING-SPECIFIC TRAINING PROGRAM ON UPPER-BODY POWER IN NOVICE CLIMBERS COMPARED TO ADVANCED CLIMBERS

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Muscular strength and muscular endurance are integral physical components of rock climbing. The hypothesis of this study was that a climbing-specific training program would improve physical fitness specific to climbing and improve performance on a relevant indoor rock-climbing test in novice climbers.

Twenty-one novice recreational climbers were matched for sex and climbing performance and randomly assigned. The experimental (EXP, n = 11) group was provided a climbing-specific, six-week training program. The control (CON, n = 10) group continued training as usual. Pre- and post-tests involved anthropometric tests, the ape-index test (arm span to height ratio), a weighted pull-up test, a bench press test, the arm jump, hand dynamometer grip strength test, and an indoor rock route of graduated difficulty for climbing performance. Testing for both groups occurred prior to the commencement of training and immediately after. A comparison group of advanced climbers (ADV, n = 14) was tested as a benchmark for change in performance in the CON and EXP groups.

Data were analyzed through one-way and two-way ANOVAs followed by Student t post-hoc tests. The ADV group was significantly better than either novice group; left hand grip strength (EXP $p = 0.010$, CON $p = 0.003$), right hand grip strength (EXP p = 0.014, CON p = 0.005), arm jump velocity (EXP $p = 0.003$, CON $p < 0.001$), arm jump power (EXP $p = 0.009$, CON $p = 0.003$), arm jump distance (EXP and CON $p < 0.001$), weighted pull-ups (EXP and

CON $p < 0.001$), body weight bench press (EXP $p = 0.039$, CON $p = 0.022$), and climbing grade (EXP and CON $p < 0.001$). Following the post-test, only the EXP group had significant improvements in the arm jump velocity ($p = 0.024$), arm jump power ($p = 0.019$), arm jump distance ($p = 0.028$), and weighted pull-ups ($p = 0.039$). Both the EXP group and the CON group significantly improved their climbing performance over their pre-test (EXP $p = 0.016$, CON $p = 0.018$). In conclusion, while both groups improved climbing ability, the experimental training program successfully improved upper body pulling strength and power.

This dissertation is dedicated to my wife, Shanna Wood. She has been my inspiration and motivation over these seven years. I would also dedicate this to my two children: Taylor and Zachary. Hopefully they can see that you can do what you put your mind to, no matter how long it takes or when you start.

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CHAPTER I

Introduction

Rock climbing has increased in popularity over the years and was even added as an Olympic sport during the 2020 Olympic Summer Games. The increase in indoor climbing facilities has made climbing more accessible and attractive as recreation. The market research group, Transparency Market Research, reports that climbing gyms in North America have experienced a 10% year-to-year growth since 2015, and that is expected to continue (TMR.com, 2021). To increase the new climber's success and enjoyment of the sport, improvement in physical fitness and climbing performance needs to be readily attained. Research on climbing performance and training has mainly focused on climber anthropometrics (Giles et al., 2006; Grant et al., 1996; Grant et al., 2001; Laffaye et al., 2016; Mermier et al., 2000; Sheel, 2004), grip and finger strength (Levernier & Laffaye, 2019; MacLeod et al., 2007), and training in elite climbers (Levernier & Laffaye, 2019; Michailov, 2014; Saeterbakken et al., 2018). Hermans et al. (2017) studied two different strength and conditioning programs on reported lower grade and intermediate climbers. The two programs consisted of either high load-low repetition or lower load-high repetition strength training. Exercises consisted of standard machine-based strength exercises with free weights only utilized for elbow flexion and forearm/finger strengthening exercises. Not included in this study's intervention were exercises to increase the power of the climber either focused on the upper body or the total body. Upper-body power has been identified as an attribute for success in indoor rock climbing, specifically bouldering (Michailov et al., 2009). Laffaye et al., 2014, validated an upper-body power test to assess power in climbers across skill levels and between sub-sets of sport climbing: bouldering and route climbing.

Including upper-body power into a training program, especially for novice climbers, may provide an overlooked stimulus to improve climbing performance and climbing fitness.

Problem Statement

Rock climbing requires muscular strength, muscular endurance, and muscular power to negotiate vertical routes. Novice climbers may have a physical fitness limitation as well as a tactical climbing limitation to overcome to be successful. Proper physical training and conditioning to enhance and maintain physical capabilities including mobility, strength, power, muscular endurance, aerobic capacity, and anaerobic capacity are necessary. Currently, there is limited research on physical training programs for novice climbers, especially that include upper-body power prescription.

Questions to be answered in this study are:

1) To what extent will a climbing-specific training program elicit physical fitness adaptations in novice climbers as measured by current physical testing protocols?
2) To what extent will this climbing-specific program improve specific climbing performance parameters including upper-body power, grip strength, and a relevant climbing task?

Theoretical Framework

Periodization is the theory of varied training stimulus over prescribed discrete time periods to elicit adaptations (Plisk & Stone, 2003). Grounded in Hans Selye's General Adaptation Syndrome, physical or psychological stress causes adaptations in an organism (Selye, 1953). In the first phase (alarm) of reacting to stress, an organism decreases in its capacities away from homeostasis and the beginning of adaptation starts. In the athletic realm, this alarm phase may be characterized by muscle soreness, stiffness, or compromise in performance. In the second phase, the resistance phase, the organism adapts to the stress through biochemical, structural, and psychological changes to return to previous capacity and may exceed that capacity. In the third phase, with proper recovery to the applied stress, there is a sustained enhancement in the organism's capability. If the stress is continued without proper recovery, then the organism will fall below its normal homeostasis into overtraining.

Block periodization is shown to be effective for developing the required physical capabilities for sport and tactical athletes (Abt et al., 2016; Ronnestad et al., 2019). The use of sequenced, focused blocks of training allows for scientific analysis of the effectiveness of training and the use of a minimum volume of training to allow for adaptation and avoid overtraining. The blocks are typically categorized as 1) Accumulation phase, 2) Transmutation phase, 3) Realization phase and 4) Transition phase (Cunanan et al., 2018). Each training phase will allow for the sequential progression from generalized abilities (e.g., aerobic endurance, strength, power) to sport or tactical specific training (e.g., maximum speed, finger/pinch strength, game-specific skill).

Purpose Statement

In this study, the researcher analyzes the impact of a climbing-specific physical training program on the physical capacities and climbing performance of novice rock climbers. This study specifically evaluated the training program's effect on upper-body power, upper-body strength, grip strength, and a climbing task.

Hypothesis

The central hypothesis of this study was that a climbing-specific training program organized in a block periodized manner with an emphasis on upper body power training would improve physical fitness specific to climbing and improve performance on a relevant climbing test in novice climbers. Subordinate hypotheses were 1) that there would be significant differences in physical performance and climbing-specific performance between advanced and novice climbers, with advanced being greater; 2) that a climbing specific strength and conditioning program would decrease the difference in physical performance and climbing-specific performance between novice and advanced climbers; 3) and the experimental group would improve physical performance and climbing-specific performance over the control group.

Methods

A quantitative experimental study assessed the efficacy of a climbing-specific physical training program. The treatment group was exposed to a 6-week, climbing-specific block periodization program while the control group continued their current training. The inclusion of a comparison group of advanced climbers for testing was used as a benchmark for change in performance in the control and experimental groups. A National Strength and Conditioning Association (NSCA) Certified Strength and Conditioning Specialist (CSCS) led the training and testing. The pre- and post-tests involved anthropometric tests, the ape-index test (arm span to height ratio), a pull-up test, a bench press test, the arm jump test (Laffaye et al., 2014), hand dynamometer grip strength test, and an indoor rock wall climbing test for relevance. All participants were volunteers from a local indoor rock-climbing gym.

Data were housed in spreadsheets and then SPSS (IBM ver 28) processed the analysis through mixed Analysis of Variance (ANOVA) with Student t post-hoc tests to determine any significant differences pre and post or between groups.

Significance

Previous researchers have examined the anthropometric and physical fitness characteristics of recreational and professional climbers (Grant et al., 2001; MacDonald &

Callender, 2011). These studies compared physiological capacities and anthropometrics across sub-disciplines: alpine, bouldering, sport route; and across skill levels: elite climbers, novice climbers, non-climbers. However, there is no published scientific research regarding climbing-specific training for novice climbers that include power training. Moreover, the results of his study may lead to training programs that enhance the tactical performance of novice climbers that accelerate their development into higher skilled athletes.

Delimitations

- Only volunteers over 18 years of age were included.
- All subjects were free of injuries that would limit their physical training or climbing.
- The focus of this training program was to enhance specific physical attributes to enhance climbing. This may mean that other physical attributes that are not specific to climbing may be temporarily compromised.

Assumptions

- Control subjects will maintain their usual training throughout the six-week period.
- All participants will be available for all testing and training sessions.

Definition of Terms

- Strength. Used interchangeably as either the isometric force created as measured with a dynamometer or concentrically as the force created to lift a measured weight.
- Power. Amount of work (force * distance) performed per unit time.

- Aerobic capacity. Amount of energy capacity produced through oxidative resources.
- Anaerobic capacity. Amount of energy capacity produced though the lactic acid and phosphagen systems.
- Anthropometrics. The measurements, proportions, and ratios of the human body to include height (cm), body mass (kg), body mass index (BMI), arm span from tip of left hand to tip of right hand (cm), and ape index ratio (arm span / height).
- Redpoint climb. Lead climbing a route that one has climbed or practiced before (such as by top rope).
- On-site climb. Lead climbing a route successfully without prior practice on the route.
- The International Rock Climbing Research Association (IRCRA). An international forum for those with interest in research in climbing. A scale created by IRCRA is commonly used to classify climbers by quantified degree of difficulty climbed.
- Novice climber. A climber whose best unassisted climb is rated below 10 on the IRCRA rating scale.
- Intermediate climber. A climber whose best unassisted climb is rated between 10 and 17 on the IRCRA rating scale.
- Advanced/elite climber. A climber whose best unassisted climb is rated 18 or above on the IRCRA rating scale.

Summary

This randomized control design study investigated whether a 6-week climbing-specific block periodized training program would improve task-specific performance training. There is little to no scientific literature quantifying climbing performance in novice climbers. The results may help expand the knowledge into developing and implementing training programs in the climbing community. Following this summary, Chapter 2 provides a review of the literature regarding periodized training, current climbing training, and current rock-climbing physical training programs. Chapter 3 details the methods of this study.

CHAPTER II

Review of Literature

Introduction

Climbing has become a popular form of recreation and exercise and has been added as an official sport in the 2020 summer Olympics (www.olympics.com). Success in either indoor or outdoor rock climbing relies on a number of factors including anthropometric characteristics (Grant et al., 2001); mental performance (Draper et al., 2010); muscular strength and endurance (Fanchini et al., 2013; Giles et al., 2006; Laffaye et al., 2016); finger grip strength and rate of force development (Bergua et al., 2018; Macleod et al., 2007); and flexibility (Grant et al., 2001). Exploration of the literature revealed research that has sought to answer various questions of what qualities make climbers different from non-climbers, how climbers of the various subdisciplines differ from each other, and how training modalities (e.g., finger board training) improve climbing ability. Most literature on climbers focuses on the physiological and anthropometric traits of advanced climbers as they would have most closely reached training or physiological potential (Abreu et al., 2019; Bergua et al., 2018; Draper et al., 2011; España-Romero et al., 2009; Fanchini et al., 2013; Levernier et al., 2019; Saeterbakken et al., 2018). Research on climbing-specific training programs to improve climbing performance and climbing fitness is also limited but includes finger strengthening (Bregua et al., 2018; Levernier & Laffaye, 2019; López-Rivera & González-Badillo, 2019; Stein et al., 2021) or general strengthening (Hermans et al., 2018; Philippe et al., 2019). Training programs for novice climbers are also limited in the literature (Hermans et al., 2017). This review of literature will examine relevant research regarding climbing disciplines, climbing-specific physiology, and climbing-specific training programs.

Climbing Disciplines

Climbing for recreation - whether by amateurs, competitors, or professionals - can be divided into three main categories: sport, traditional, and alpine. Sport climbing can take place indoors or outdoors and may consist of climbing on taller walls (12-18 m) or shorter boulders (4-5 m) where athletes are required to figure out complex routes to climb (Fanchini et al., 2013; Phillips et al., 2012). On taller walls/problems, the climber is protected either by a top rope or by clipping a trailing rope into pre-placed points of protection. Traditional route climbing takes place outdoors and requires lead climbing and top-rope techniques to climb "pitches" on the ascent. The lead climber on "trad" routes must carry metal devices to insert into cracks in the rock, and then clip the trailing rope to these devices for protection. A pitch is a portion, or stage, of the ascent that the climbers must negotiate before they can progress further. It usually requires hauling ropes and protective gear up for each stage. Alpine climbing is an endurance event that may take several days to weeks or months. It combines backpacking and hiking, lead climbing, multipitch climbing, snow and ice negotiation, and exposure to extremes in temperature and altitude (House & Johnston, 2014; Mermier et al., 1997).

Climbing as an occupation may be found in industry (telecommunications infrastructure, oil platforms) first responders and the military. Such occupational climbing may involve components of one or more climbing disciplines, usually while carrying heavy gear that is not required in civilian recreational or sport climbing, i.e., rescue or combat mission gear and body armor. In the military, climbing may involve moving off a boat onto a moving ship or a tall gas and oil platform, and it involves fixed ladders or ropes placed by a lead climber. Climbing a wall or onto a small building is much like a bouldering problem, but with heavy gear.

Physiology of Climbers

Anthropometrics

Anthropometrics have been studied to gain insight into what makes elite climbers. Anthropometric tests include height, body mass, body fat percentage, arm length, leg length, hand length, ape index (arm span/height), and bone density. España-Romero et al. (2009) performed a comprehensive study on expert (< 75^{th} %tile in climbing ability) and elite ($\geq 75^{th}$ %tile) climbers of movement-based anthropometric characteristics of the upper body. They showed no significant difference in characteristics like forearm bone density, forearm lean mass and fat mass based on dual x-ray absorptiometry studies between the elite and expert groups. Significant findings between sexes were noted, though, with males being taller and having more lean tissue and less fat mass than females. MacDonald et al. (2011) found similar results comparing boulderers with matched aerobically trained non-climbers. Only forearm bone mineral density and finger flexor re-oxygenation time were significantly different (greater) in climbers than non-climbers. The re-oxygenation time was found to be related to the force-time integral of the maximum voluntary contraction (MVC) test. Laffaye et al. (2016) only found that ape index was significantly larger in expert and advanced climbers than in novice climbers (1.03 vs. 1.00). Merrimer et al. (2000) used principal component analysis and multiple regression to analyze 29 variables in 44 recreational climbers to assess which variables contributed most to climbing performance. Three components were identified: training, anthropometrics, and flexibility. The 29 variables were reduced to 17 and grouped by commonality. The analysis placed hip flexibility into the flexibility component, which explained only 10 percent of climbing performance, while the anthropometrics component, which ape index fits into, explained 15 percent of climbing performance. The training component explained 39 percent of the variability in climbing performance and was the only statistically significant component. Grant et al. (1996), however, found hip flexibility was a significant contributor to the success of climbers. They compared the anthropometric, strength, endurance, and flexibility characteristics in elite climbers, recreational climbers, and non-climbers. For anthropometrics, height, body mass, body composition, arm span, and leg length were measured. Strength was tested by hand grip dynamometry and by finger dynamometry. Endurance was tested by pull-ups, bent-arm hang, and sit-ups. Finally, flexibility was tested by leg span and a standing hip flexion test. When normalized to leg length, Grant et al. found that elite climbers had a significantly greater (p = 0.02) leg span than recreational climbers or non-climbers. The leg span measurement was to mimic the bridging movement made by climbers when on a rock face. No effect size was provided.

Cardiovascular

Maximal aerobic capacity and blood lactate have been tested to measure cardiovascular endurance and fatigue in climbers. Michailov et al. (2015) compared VO_{2peak} and blood lactate measures of elite sport climbers (redpoint grade = Fr.8b) during treadmill (TMT) and upper body ergometry (UBT) tests. Maximal blood lactates levels were found to be similar between testing modes (TMT 12.3 mmol/L; UBT 11.9 mmol/L) while VO_{2peak} was found to be lower in UBT than TMT (34.1 mL*min^{-1}*kg^{-1}; 58.3 mL*min^{-1}*kg^{-1}). These values were higher than in studies that measured cardiovascular parameters during climbing. Billat et al. (1995) studied cardiovascular requirements and blood lactate levels in competitive college age climbers on two similarly graded routes (Fr.7b), with the first route being more technically complex and the second route being more physically demanding. Each route took between 3 and 5 minutes to complete as reported. They reported blood lactate levels of 5.7 mmol/L for the first route and 4.3

mmol/L for the second route. While oxygen consumption was not measured during the climbing tasks, heart rate was, and it reached 84% and 71% of treadmill maximum on the two routes, respectively. They noted that, while high aerobic capacity was not required, the ability to handle moderately high blood lactate levels would be of importance in climbing. In a study by La Torre et al. (2009), a group of elite Italian boulder climbing athletes were tested for blood lactate immediately following climbing during a national bouldering competition and a second group of such athletes were tested for blood lactate and heart rate during a simulated bouldering competition. Climber HR was not studied during the national bouldering competition as rules would not allow for any monitoring during the competition. Elite climbers were found to have HR values that were about 73% of age-predicted maximum during the simulated bouldering competition. It was also found that a large portion of the climbing (40%) was in the < 60% HR_{max} range. Even though HR during simulated competition did not exceed 60% HR_{max} for much of the climbs, the blood lactate was found to reach 5.6 mmol/L, compared to 6.9 mmol/L during the national boulder competition. The relatively high lactate in that study compared to HR may be due to repeated isometric contractions during climbing.

Muscular

Muscular strength can be divided into general strength and specific strength. General strength refers to the ability to produce force and power in manners that are common to all sports and physical activity. Tests for general strength may include the bench press, pull-up, squat, deadlift, and variations of these tests. Studies have not shown elite climbers to possess greater specific strength than novice climbers and sometimes less general strength than novice climbers. Laffaye et al. (2016) demonstrated that elite climbers exhibited lower force and power on bench press than did novice climbers (65.1 kg vs 69.7 kg and 601 W vs 653 W, respectively). Macias et al. (2015) demonstrated in a study of rock (boulder) climbing males, that rock climbers performed more pull-ups than did resistance trained males (19.3 to 15.6 repetitions). In a study on physical fitness parameters (Wood & Swain, 2021), Navy Special Warfare lead climbers demonstrated greater strength than non-lead climber Navy special operators. This retrospective study reported an average body mass for lead climbers of 89.4 kg compared to non-lead climbers of 85.8 kg. The lead climbers' performance of weighted pull-ups (25 lb) (16.2 repetitions) was non-significantly higher than non-lead climbers (15.1 repetitions). The lead climbers' performance of the 1-RM deadlift (206.9 kg) was significantly higher ($p = 0.002$) than the non-lead climbers (178.7 kg).

For climbers, specific strength, especially specific strength relative to body mass, becomes critical. Grip strength, finger strength, shoulder girdle muscular endurance, and upper body pulling power have been tested to determine if these parameters predict climbing performance. Laffaye et al. (2016) reported that elite climbers produced more force than did novice climbers with finger grip strength (330 N vs 186 N) and upper body pulling power as indicated by distance in the arm-jump test (76 cm vs 36 cm). Macias et al. (2016) reported that accomplished rock climbers (boulder) had an average pinch grip of 176 N. These results are comparable to the novice climbers and not the elite climbers from Laffaye et al. (2016) and are indicative of climbers who have less climbing training than elite climbers. The participants in the Macias study averaged two years of climbing training, whereas to be included in the Laffaye study, the participants were required to have at least three years of training.

Vascular

Vascular changes have been highlighted as a potential mechanism that separates elite climbers from expert or novice climbers. Ferguson and Brown (1995) performed a novel set of blood pressure tests on elite climbers and sedentary individuals. The authors measured forearm blood pressure response to sustained isometric contraction, at 40% MVC, and to rhythmic isometric contraction. Rhythmic contraction consisted of 5 s contraction at 40% MVC and 2 s recovery until voluntary ending. It was found that elite climbers and sedentary individuals had similar sustained isometric blood pressures but that elite climbers had lower blood pressure during rhythmic isometric contraction pointing to a better attenuated pressor response. Fryer et al. (2015) used infrared spectrometry and Doppler ultrasound to examine if either forearm blood flow dynamics or muscle oxygenation capacity was indicative of climbing performance in non-climbers and three levels of climbers (intermediate, advanced, and elite) during climbing-specific isometric contraction. Their results showed that there was no significant difference between the climbing groups with regard to blood flow during isometric contraction, but there were significant differences between the groups for tissue de-oxygenation. The data showed that the elite climbing group had a significant difference in tissue de-oxygenation compared to all other groups for the flexor digitorum profundus muscles and a significant difference compared to the advanced group for the flexor carpi radialis. The increased de-oxygenation for the elite climbers for similar work compared to the other groups was hypothesized to show an increase in oxygen utilization due to improved tissue profusion resulting from vascular adaptations from training. These results are similar to findings by Kodejška et al. (2015) who studied de-oxygenation in forearm musculature in boulder and lead climbers during isometric contraction. Kodejška et al. used a higher sustained isometric contraction than did Fryer et al. (60% vs 30%) but found the same de-oxygenation of the flexor digitorum profundus. The results of both these studies would suggest that blood hemodynamics play a much smaller role in climbing performance than does oxidative capacity of the muscle tissue.

Physical Training for Climbers

For climbers of all disciplines, relative strength is crucial to success. Relative strength is the amount of force produced relative to body mass. High relative muscular strength, especially upper body strength, relative to body mass would theoretically allow the climber to perform better than climbers with low relative strength. Having higher relative strength would provide the benefits of injury prevention (stronger shoulder girdle), increased ability to maintain contact with a hold (stronger hand/finger grip) and be able to move/propel the body better (more pull-ups), as were shown in previous studies (Macias et al., 2015; Mermier et al., 2000). In 2017, Hermans et al. studied the effect of a 10-week high repetition-low load training versus low repetition-high load training on climbing performance in 30 novice and intermediate climbers (grade 8-13 on the IRCRA scale). Pre-testing included a climbing performance test utilizing an 18-m climbing wall route graded at an IRCRA 13, a bent-arm hang for upper body isometric muscle endurance, a dead hang test for finger and forearm isometric strength and endurance, and a 12-RM cable pull-down for upper body muscular strength-endurance. The thirty participants were randomly divided equally into one of the two training groups or a control group. Each training group performed the same seven exercises: pull-down, seated bench press, seated row, seated shoulder press, bicep curl, forearm press, and forearm curl. Strength training in both groups occurred two times per week, for 10 weeks, with the high resistance-few repetition group performing four sets of 5 repetitions with a 3-minute rest between sets, and the low resistance-high repetition group performing two sets of 20 repetitions with a 2-minute rest between sets. The results showed that there was not a statistically significant difference in climbing performance between the two intervention groups, but there was a trend (p = 0.088-0.090) for overall improvement in climbing performance: 4% in the control group, and 11% and 12% in the high rep-low load group and the low rep-high load, respectively. While the control group reported twice as many climbing sessions as the intervention groups during the 10-week period, they averaged just over one climbing session per week while the training groups averaged just under one climbing session per week. This lack of actual climbing may factor in the limited improvement in climbing for all groups.

The capacity to resist fatigue while holding onto the surface or pulling oneself up to another hold is an important climbing ability. Physical training for climbers traditionally involves body weight-based training but will also include isometric training and strength training. In 2018, Saeterbakken et al. studied the effect of a progressive isometric versus progressive dynamic core strengthening program on advanced climbers (> grade 15 on the IRCRA scale). Nineteen climbers were randomly assigned into either a 10-week dynamic or isometric training group. There was no control group included. Testing included isometric and dynamic, climbing-specific and non-climbing specific tests. The isometric tests included the body lock-off test (climbing-specific) and tests of trunk strength in flexion, and in right and left rotation (non-climbing specific). The three non-climbing specific isometric tests were measured with a dynamometer. Dynamic tests included the body lift test (climbing-specific), and the Superman test (non-climbing specific). The Superman test is a dynamic prone plank test. An isometric finger hang test was used as a climbing-specific test. Participants used a half-crimp grip to hang from a 2.5-cm campus board for time. At the end of the 10-week training program, there were significant improvements in abdominal flexion by both groups, in body lift by the isometric group (and a trend, $p = 0.010$, by the dynamic group), and in the Superman by the dynamic group. But none of the improvements significantly differed between the two groups.

A physical training study of lead climbers, Philippe et al., 2019, examined the effects of two different training methodologies on lead climber performance. Twenty-five advanced climbers who self-rated as ≥ 17 IRCRA (≥ 8 Union Internationale des Associations d'Alpinisme, UIAA) were randomly assigned to a muscle endurance or muscle hypertrophy training program. The exercises for each group were the same but the load and repetitions were specific to each group with the hypertrophy group working in the 10-12 repetition range and the endurance group working in the 15-50 repetition range. Exercises included campus board training, bouldering moves, and lead climbing moves of various difficulties instead of traditional weightlifting exercises specific to climbers. Each program lasted 8 weeks with a pre- and post-climbing specific test of on-site climbing to determine change due to the training programs. Results showed that there were significant improvements over time for both groups for climbing moves ($p = 0.001$), climbing difficulty ($p = 0.001$), time to climb ($p = 0.044$), and moves per time ($p = 0.010$), but no significant differences in any of these measures between the groups. The authors concluded that both the hypertrophy and endurance training programs elicited improvement in the climbing tests because climbing requires both climbing-specific strength and climbing-specific endurance to be successful.

Previous training programs also focused on reducing body fat mass, increasing lean tissue, and improving finger strength and rate of force development (RFD) (Fanchini et al., 2013; Levernier & Laffaye, 2019; Mermier et al., 2000; Watts, 2004;). Levernier and Laffaye (2019) studied 14 elite French climbers (> 26 IRCRA scale), to determine if a 4-week finger strengthening program would improve finger strength and RFD. High RFD is important for quickly securing grasp of holds, thus improving the performance of the climber. The climbers were randomly assigned into a control group (no special training intervention) and the experimental group that included isometric finger strengthening 2 times per week for 4 weeks. The strengthening exercises included single arm isometric hangs from three different positions:

slope, half crimp, and full crimp. Each exercise was performed twice for 4-6 seconds with 3 minutes rest between. At the end of the 4 weeks of training, the authors reported that there was no significant difference between the groups regarding increase in absolute finger strength ($p \geq 0.05$) but when normalized to body mass the experimental group had significant improvement ($p = 0.02$). No significant difference between groups was found for RFD. What they reported as significantly different was an improvement in the experimental group's RFD at 200 ms ($p = 0.009$), which the authors attributed to improved neural tone, not tendon or muscular change. In this study, no practical climbing-specific test was used to determine if climbing performance improved with training.

Stein et al. (2021) studied 16 advance climbers (> 18 IRCRA scale) who were randomly assigned to either a control group, a 2 times per week training group or a 4 times per week training group. Testing included a bouldering problem rated at 22-23 IRCRA, a maximal reach test on campus boards, a maximal isometric pullup measured against a force cell, and a campus board climb to failure test. The training intervention was built around training on campus boards with various dynamic and static training exercises. The boards measured 25, 20, and 15 mm in depth. The exercise prescription was a total of 4 exercises. The twice a week group performed all four exercises on both training days. This training took 40 minutes per session. The four times per week group performed only two exercises during each block but performed each exercise twice over the four days. This training took 20 minutes per session to perform. At the end of the training, the two times per week group had a significant improvement in bouldering performance ($p = 0.016$) while the four time per week group and control group did not. When combining the two training groups, there was improvement over the control group in bouldering performance (p

= 0.006), force in the jug position ($p = 0.015$), absolute rate of force development ($p = 0.023$), maximal reach ($p = 0.040$), and maximal moves ($p = 0.040$).

Of the studies that included campus board or finger board testing (Bergua et al., 2018; Levernier & Laffaye, 2019; López-Rivera & González-Badillo, 2019; Macleod et al., 2007; Philippe et al., 2019), no study had novice climbers as subjects. With the growth of climbing as a sport and recreational activity, newer or novice climbers will begin training programs. Understanding how this training may improve their climbing ability earlier would be beneficial. The proposed study will seek to have novice climbers train with campus boards as well as climbing-specific strength exercises.

Climbers have employed a combination of body weight training and isometric holds to improve muscle stiffness, endurance and to optimize their ability to move and support their bodies through space going up a wall or boulder. Pull-up and pull-up variations are a staple for shoulder girdle and upper extremity strength and muscular endurance. Gymnastic training may be suitable for climbers looking to develop kinesthetic awareness, muscle force and endurance. Isometric muscular contractions are contractions, either maximal or submaximal, of a muscle or muscle group where there is no movement at the joint that the muscles attach to. Isometric contractions are performed frequently during climbing to maintain grip on a hold, to fix the lower extremity between two holds to free up the hands (knee bar) or to perform a friction hold like a mount or a mantle (Phillips et al., 2012). Training for isometrics can include grip strength exercises or prolonged holds during body weight exercises to increase muscular force and tension while developing fatigue resistance within the muscle.

To develop maximal strength, external resistance must be applied to the body. Weighted pull-ups, deadlifts and squats, weighted finger strengthening, and presses develop the structural strength and neural adaptation to moving heavy weight. Higher intensities, greater than 90% of the individual's 1-repetition maximum, will positively affect maximal strength and rate of force development (neural adaptation) (Stone et al., 2007). While greater strength is advantageous to climbers, muscle hypertrophy and thus increased mass may be counterproductive. An increase in maximal strength without a large increase in body mass will improve the relative strength of the climber (Phillips et al., 2012). A judiciously designed training program that increases intensity while keeping total volume modest may be preferred for achieving this goal.

The theory of periodization places specific training blocks into discrete time periods to prepare an athlete for competition (Stone & Plisk, 2003; Issurin, 2010). These discrete time periods are planned and sequenced to provide the proper dosing of stimulus and recovery to affect the adaptations desired leading up to a competition. They are arranged from large time blocks to small time blocks. Macrocycles last up to a year and are made up of smaller mesocycles that last weeks, which in turn may consist of microcycles that last for up to a week. Macrocycles typically consist of three mesocycles (accumulation phase, transmutation phase, and realization phase) and a competition period. The first mesocycle phase is called the accumulation phase. The priority of this phase is the development of general physical fitness that sport-specific fitness and tactical skills will be built upon. These general fitness parameters include aerobic fitness, general strength and power, and proper movement. The second phase, transmutation, develops sport-specific fitness and includes tactical preparation. This includes anaerobic fitness, speed-strength or muscular endurance, and tactically relevant skills. In the final phase, realization, the program focuses on restoring the athletes so that they are ready to compete and to enhance specific tactical skills (Cunanan et al., 2018; Innsurin, 2010). Since periodizing training calendars are arranged around competition, flexibility can be built into the training calendar to meet schedules and goals.

In the context of this dissertation, the block periodization will be broken into two three-week periods. During the first block (phase) the emphasis will be on strength training to improve strength of the upper extremities, shoulder girdle, and core to prepare for the introduction of the upper body power training in the second phase. In this first phase, eccentric strength, maximal effort, rate of force development, and recovery would be the priorities of the program. During the second and final phase, muscle power and grip/finger strength would be emphasized. Intensity of training and volume would both be high to develop the tensile strength of the tendons and muscle fibers and prepare the climbers for higher graded climbs. This phase will also include climbing specific isometric and body weight training to elicit the desired increase in relative strength and increase in muscle fatigue resistance.

Summary

Recreational climbing including traditional climbing and sport climbing requires high degrees of upper body muscular endurance, flexibility, and grip strength to be successful (Fanchini et al., 2013). Anthropometric and physical characteristics of advanced and elite level climbers have been studied (Bergua et al., 2018; Draper et al., 2010; Fanchini et al., 2013; Giles et al., 2006; Grant et al., 2001; Laffaye et al., 2016; Macleod et al., 2007). Specific training programs or applications have been studied using expert and elite climbers to determine if such training would improve climbing performance in high level climbers (Abreu et al., 2019; Bergua et al., 2018; Draper et al., 2011; España-Romero et al., 2009; Fanchini et al., 2013; Levernier et al., 2019; Saeterbakken et al., 2018). Research on novice climbers is more limited including climbing-specific training programs (Hermans et al., 2017). This study will look to add to the literature by investigating the effects of a climbing-specific training program on the climbing performance of novice rock climbers.

CHAPTER III

Methods

Introduction

The purpose of this study was to analyze the impact of a climbing-specific physical training program on the physical capacities and climbing performance of novice recreational climbers. Specifically, the researcher evaluated the climbing-specific training program's effect on upper-body power, upper-body strength, grip strength, and performance on a climbing task. Two questions that the researcher aimed to answer are: 1) To what extent did a climbing-specific training program elicit physical fitness adaptations in novice climbers? 2) To what extent did this climbing-specific program improve climbing performance parameters including upper-body power, grip strength, and graded climbing tasks?

Research Design

A quantitative experimental research design was used for this study. This study utilized a matched, randomized, unblinded, parallel-group design (novice climbers) and included a third, non-randomized advanced climber cohort. The non-randomized cohort served as a comparator to assess the effectiveness of the proposed climbing-specific block-training program.

Research Ethics and Human Subject Protection

All researchers connected to this study completed and were up to date on their human participants protection and research ethics training and certifications (CITI) at the time of this study. This study had approval from the Old Dominion University Institutional Review Board before beginning. The researchers also obtained written permission to conduct the research from the indoor rock-climbing facility where the study was performed before the commencement of the study. The procedures and risks of the study were described to potential participants, and those volunteering gave written informed consent.

This researcher did not have any affiliation with the indoor rock-climbing facility that could be seen as undue influence in recruiting participants.

Population and Sample

A goal of 45 recreational climbers were to be recruited for this study: 30 novice and 15 advanced. The novice climbers were matched for sex and climbing performance based on a pre-test progressively graded climb and were then randomly assigned into either the treatment group (n =15) or the control group (n =15). Recreational climbers were considered novice climbers if their best top-roped but unassisted climb was rated below a 10 on the International Rock Climbing Research Association (IRCRA) scale. The IRCRA scale has been used in current literature to determine climbing ability (Hermans et al., 2017; Michailov et al., 2018; Philippe et al., 2019; Stein et al., 2021). Climbers were considered advanced if their best climb was rated an 18 or above on the IRCRA scale. The IRCRA scale (Table 1) rates the difficulty of climbs and incorporates previously established rating systems, i.e., the Yosemite Decimal System, the French sport climbing system, and others (Draper et al., 2015). Research has demonstrated that climbers are able to accurately self-report their climbing ability (Draper et al., 2011). Subjects were asked to report their best top-rope climb (without assistance from the rope/belayer) within the past three months. All subjects were recruited through word of mouth and poster advertisements.

Inclusion

Participants that were eligible for inclusion in this study were current recreational climbers. All participants must have been between 18 and 55 years of age to participate.

Exclusion

Exclusion criteria for this study are:

- Participants with a diagnosed medical condition that would prohibit them from participating in strenuous activities such as climbing, lifting heavy weights, or intense cardiovascular training.
- Participants having an injury to the upper or lower body that may prevent full performance on any of the physical tests or training programs are not eligible for this study
- Injuries that would exclude a subject are acute injuries that require missed workdays during the study

Examples of injuries that would exclude a subject are acute injuries to the tendons, ligaments, or capsule of the shoulder or elbow; acute injuries to the muscles of the shoulder or elbow; acute injuries to the tendons, ligaments, or capsules of the wrist and hand; acute injuries to the tendons, ligaments, or capsule of the hip, knee, or ankle; acute injuries to the muscles of the hip, thigh, or lower leg; chronic pain or injury to the spine, upper or lower extremities that prevent the subject from fully participating in regular physical training programs or climbing training.

Population

Participants in this study were recruited from the local climbing population, male and female, and were between the ages of 18 and 55 years old. Latitude Climbing, LLC is located in Virginia Beach, VA, and all participants were residents of the surrounding Hampton Roads area.

Measures and Covariates

Primary measures collected by the researchers for the experimental group and control group were pre- and post-test results of climbed height and time to ascend a marked indoor climbing route, distance on the arm jump test, and strength on the grip test. Secondary measures recorded to assess increases or decreases in non-climbing-specific, upper-body muscular strength and power: maximal repetitions of the 11.4-kg weighted pull-up and the body-weight bench press. All primary and secondary tests were performed once on the group of advanced climbers.

Anthropometric Tests

Anthropometric measurements included subject's body mass, height, arm span, ape-index (subject arm span/height), and BMI. The subject's height was measured in cm using a stadiometer. Arm span was measured while the subject was standing with his or her back to a wall, arms extended out from the side at 90 degrees. A mark was made at the tips of the fingers on each hand and the distance, in cm, was measured between the two marks with a flexible medical tape measure. The ape-index was calculated by dividing the arm span by the subject's height. Body mass was assessed by digital scale (Healthometer 498KL, Sunbeam Inc) and BMI was calculated as body mass divided by height squared.

Physical Fitness Tests

Physical fitness tests included the arm jump test (Figure 1) (Laffaye et al., 2014), handgrip strength, 11.4-kg weighted pull-up, and body-weight bench press. No verbal encouragement was provided to the subjects during any of the pre or post testing. The arm jump test, as described by Laffaye et al. (2014), showed excellent inter and intra-session reliability for determining power production and jump height (ICC >0.95). To perform the test, a linear positioning transducer specific for measuring the speed of movement in the weight room (TendoSport) was fixed to the subject's waist at the beltline. The subject then hung from two climbing holds fixed at a level above his or her reach (Fig. 1). On the subject's volition, the subject explosively pulled-up and then reached and touched a metered board above the holds with both hands as high as possible. The height reached by the tip of the finger of the lower hand was the recorded mark. The participants were allowed three attempts and the highest mark was counted. Distance of reach, distance of elevation from the accelerometer, and peak speed of the linear transducer were recorded. Power (watts) was calculated from force (mass x acceleration) times distance (m). The participants had assistance in returning to the ground for safety.

Handgrip strength was measured with a Jamar hand-grip dynamometer with the subject standing with the testing arm abducted 20 degrees and the elbow extended. The dynamometer was set so that the middle phalangeal joint is at a 90-degree angle. On command, the subject performed a maximal isometric contraction. The subject was given three attempts with the greatest measure being recorded. The validity of the Jamar hand dynamometer has been shown to be excellent (r=0.9997) as compared to other dynamometers with known weights by Mathiowetz (2002).

As described in Wood and Swain (2019), the 11.4-kg (25-lb) weighted pull-up test is a standard upper-body strength test in some Special Operations communities and a required test for certain performance batteries. A 25-lb plate was suspended from a “dip belt” worn around the waist. The subject started the pull-up from a dead hang with shoulders and elbows fully extended and with palms facing away (pronated grip). The exercise commenced on the start of the tester and concluded when the subject was no longer able to successfully complete a repetition or voluntarily stopped. Repetitions were counted when the participant cleared the chin over the bar and then the subject returned to the full dead-hang position. No kipping or swinging was allowed. One attempt was allowed for each subject.

The body-weight bench press is another standard test and is described in Wood and Swain (2019). The subject’s body mass was determined during the anthropometric assessment. A weight within 1 kg of his body mass was put on the bar. The participant was instructed to keep his or her feet flat on the floor and hips, shoulders, and head on the bench at all times, and to lower the bar under control. A hand position just outside the width of the shoulders was recommended and control of the bar during lowering and raising the bar was emphasized. For a repetition to count, the bar must have traveled from the fully extended position to touching the chest and return to a fully extended elbow position. Bouncing the bar off the chest or not achieving a fully locked out position negated the repetition. A spotter could assist in lifting the bar from the rack but if the spotter touched the bar at any time during the test, the test was concluded. One attempt was allowed for each subject. The subject was instructed to perform as many repetitions as possible without sacrificing form.

Climbing Specific Test

Primary instrumentation for external validity was a 16-m indoor rock-wall route graded at a level of 13 (IRCRA scale) as determined by an expert in designing and grading climbing routes. Participants were allowed to familiarize themselves with the route to reduce any variance from having to learn the route during the test by climbing the route to 8 meters in order not to induce fatigue (Billat et al., 1995; Hermans et al., 2017; Mermier et al., 1997). For safety reasons, each climber was top-roped with no tension in the rope to aid the climber. The rope is to prevent striking the ground if the climber falls. Timing started on a "go" command from the researcher and stopped when the subject touched a predetermined mark at the end of the course. Each subject was given two attempts at the climb with 15 minutes between attempts. The fastest time to the final hold, or the highest hold touched prior to stopping, was recorded (Hermans et al., 2017). When multiple subjects were tested in a short time frame, they were not allowed to watch the other climb the route. The same exact route was used for pre- and post-testing, so the participants were instructed to not climb the route during the training phase so that the study participants were not able to improve performance through repeated training on the route.

Training Programs

The training program for the experimental group was organized into two 3-week blocks. Each week included three days of climbing-specific strength training, two days of actual climbing, and two days of rest. The days of climbing-specific strength training were separated by at least one day of climbing or rest. Climbing-specific training exercises that were limited to the experimental group were campus board exercises, dead hangs, tempo pull-ups, velocity-based pull-ups, weighted pull-ups, and single arm lockoffs. Supervision of training was by the lead author. The lead author supervised the study participants during initial instructions, pre- and post-testing, and during the transition from training block 1 to training block 2. During the first block, each day started with injury prevention exercises: total body flexibility and mobility exercises, shoulder girdle and shoulder stability exercises, and finger conditioning and strengthening exercises (Table 2).

Day 1 included finger strengthening, pull-ups, isometric dead hangs, and pushups. Day 2 included tempo pull-ups (3 count lower/1 count rise), single arm dumbbell rows, and overhead pressing. Day 3 included inverted rows, single-arm rows, and core exercise (L sits). Each of the exercises for each training day progressed by intensity (increased weight or velocity of action), volume (repetitions), or time duration over the following two weeks.

In the second three weeks of training, the experimental program progressed from the first phase of the program with the addition of focused velocity-based training and the addition of weight to the bodyweight training exercises (Table 3). This bodyweight-plus training would enhance the climbing-specific requirements of isometric holds and the ability to create tension throughout the system to maintain grip and execute climbing maneuvers (Phillips et al., 2012). Grip training would be enhanced with specific finger and grip strengthening exercises to include maximal grip strength training and progressive training on climbing boards that are designed to increase finger rate of force development (RFD) (Levernier & Laffaye, 2019). Day 1 included weighted pull-ups, jumping pull-ups, and band-resisted pushups. Day 2 included velocity pull-ups based on the velocity recorded during the arm jump test, single-arm dumbbell rows, and a 3-position isometric hold push-up. On the first day of velocity-based pull-up training, each subject was attached to the transducer and taught the proper speed to utilize based off pre-test arm jump speed. Verbal cues and visual cues from the Tendo unit were used to ensure understanding (Weakley et al., 2020). Day 3 included inverted rows, single-arm lock offs, dips, and core exercise. Each of the exercises for each training day was progressed by intensity (increased weight or speed or action), volume (repetitions) or time duration over the following two weeks.

The control group was instructed to not utilize the climbing-specific exercises listed above but could continue with their personal training programs. Daily recording of exercises, volume, intensity, and duration were to be written down in journal format. Progression of intensity or duration was documented. The frequency and duration of climbing was also be recorded. Each participant in both groups utilized a personal journal for recording and to maintain confidentiality. Frequent, weekly reminders were sent to the control group participants to record their activity and then to send the journal to the researcher.

Data Collection

Data collection took place during two formal testing periods and then informally during the six weeks of the experimental training. The testing battery was conducted in the following order: anthropometrics, BMI, grip strength, arm-jump test, weighted pull-up, body-weight bench press, and rock-wall climbing test. This testing battery was administered prior to the first week of training. All data were collected on the subject's individual data collection sheet, then transposed into a secure spreadsheet for analysis.

The second formal data collection point occurred after the end of the 6 weeks of training. The same testing battery was used as in the first data collection point. Scores were recorded on the subject's data collection sheet and then transposed into the secured spreadsheet for analysis.

During the training blocks, changes in the amount of weight lifted during any exercise or the number of repetitions achieved during training was captured on an electronic training log. This training log enabled the participants to record weights and repetitions in a simple and de-identified manner. The changes in weights and repetitions were transferred to the secure spreadsheet for analysis.

Data Analysis

All data were de-identified when placed in the password-protected spreadsheet and stored on a secured computer not owned by Old Dominion University. The de-identified data were then cleaned for repeated or incomplete tests before analysis and then analyzed with SPSS statistical software (IBM ver 28). Each variable was assumption tested before the statistical analysis. Statistical analysis included pre- and post-test analysis. To determine any differences between each novice climbing group's pre-test values and the advanced climbing group's single set of values, a one-way ANOVA was used with Student t post-hoc tests applied to any significant findings. A two-way ANOVA (group x trial, with repeated measures on trial) was then used to test training effects in the experimental and control groups, with Student t post-hoc tests applied to any significant findings. A final one-way ANOVA for differences between each novice climbing group's post-test values and the advanced climbing group's single set of values was used. Student t post-hoc tests were applied to any significant findings. Significance was set at $p < 0.05$. To control for false discovery rates among the multiple measures, the Benjamini-Hochberg procedure was applied to the variables for both pre- and post-test one-way ANOVAs and the two-way ANOVA (Benjamini & Hochberg, 1995). To examine the factors that may contribute to arm jump distance performance, a multi-variate analysis was performed after the pre-test and post-test. Reporting included significant findings, confidence intervals, and effect sizes.

Limitations

The primary limitation of this study was the open environment instead of a laboratory environment that this study involved. This environment makes standardizing times and locations of testing and training prohibitive. The differing work schedules and frequent work travel necessitated a flexible training schedule and portable training plan. While all testing was carried out in the same facilities with the same researchers, the time of day of testing was not the same for all participants.

A second limitation of this study could be the use of the indoor rock climb as a test for external validity. While climbing an indoor rock wall may be classified and graded by experts, the routes will not be able to be recreated in other settings.

A third limitation of this study was the ability for onlookers, not associated with the study at the time, to watch subjects climb and therefore get foreknowledge of the climbing route if they were to later join the study.

CHAPTER IV

Results

In total, 46 participants were initially pre-tested for this study, 19 female and 27 male. Following pre-testing, 14 rated as advanced (ADV) climbers (3 F, 11 M); 8 rated as intermediate climbers (3F, 5M); and 24 rated as novice climbers (13 F, 11 M). The intermediate climbers were not included in this study, and three novice participants (2 F, 1 M) withdrew for personal reasons. Therefore, 35 total participants were included: ADV (3 F, 11 M) and novice (10 F, 11 M). Among the novice participants was the experimental (EXP) group (5 F, 6 M) and control (CON) group (5 F, 5 M).

Anthropometric measurements are listed in Table 4. Significant differences were found between the CON and EXP group for age ($p = 0.049$) and BMI ($p = 0.044$) with the EXP group being older and having higher BMI.

ANOVA analysis of the pre-test performance measures is detailed in Table 5. A Benjamini-Hochberg (B-H) procedure was applied to limit any false discovery rates from the multiple comparisons (Table 6). Following the B-H procedure, significant findings were then analyzed with Student t post-hoc tests between the ADV group and the two novice groups (EXP and CON). The ADV group demonstrated significantly higher scores than the CON and EXP groups for pre-test grip strength left hand ($p = 0.003$ and $p = 0.010$, vs CON and EXP, respectively) (Figure 2) and right hand ($p = 0.005$ and $p = 0.014$, vs CON and EXP, respectively) (Figure 3), arm jump peak velocity ($p < 0.001$ and $p = 0.003$, vs CON and EXP, respectively) (Figure 4), arm jump peak power ($p = 0.003$ and $p = 0.009$, vs CON and EXP, respectively) (Figure 5), arm jump distance ($p < 0.001$ for both novice groups) (Figure 6), weighted pull-ups ($p < 0.001$ for both novice groups) (Figure 7), and body weight bench press ($p = 0.022$ and $p =$

0.039, vs CON and EXP, respectively) (Figure 8). No significant differences were noted between the control and experimental groups for any pre-test variable.

Studying the factors that may have contributed to the performance differences in pre-test arm jump distance between groups, multivariate ANOVA showed that an increase in weighted pull-up repetitions was the only factor significant for the arm jump (Table 7). Using Wilk's lambda, there was a significant positive effect of weighted pull-up on the arm jump distance, $\lambda = 0.144$, $F(3, 26) = 53$, $p < 0.001$.

Post-test analysis of performance measures comparing the two novice groups to the ADV group are detailed in Table 8. A B-H procedure was again applied to limit any false discovery rates from the multiple comparisons (Table 9). Student t post-hoc tests then demonstrated significantly greater performance between the ADV group and the two novice groups (EXP and CON) for the IRCRA grade (p <0.001, EXP and CON); arm jump distance ($p = 0.003$ and p <0.001, vs EXP and CON, respectively); arm jump peak velocity ($p = 0.022$ and $p < 0.001$, vs EXP and CON, respectively); the 11.4-kg pull-up ($p = 0.015$ and $p < 0.001$, vs EXP and CON, respectively). The ADV still performed significantly better for arm jump power than the CON group ($p = 0.004$) and the body weight bench press ($p = 0.033$). However, grip strength was no longer significantly less for either novice group compared to the ADV group; left grip strength versus the EXP group ($p = 0.076$) and versus the CON group ($p = 0.078$); right grip strength versus the EXP group ($p = 0.075$) and versus the CON group ($p = 0.071$).

Two-way ANOVAs for pre- to post-test performance changes were performed between the novice groups as shown in Table 10. A B-H procedure was again applied to limit any false discovery rates from the multiple comparisons (Table 11). For each performance test, there was no overall significant difference between groups. Post hoc Student t tests demonstrated a significant increase in IRCRA rating for both groups (EXP $p = 0.016$; CON $p = 0.018$) but no difference between groups ($p = 0.434$) (Figure 9). For arm jump velocity, only the EXP group had a significant increase ($p = 0.024$) (Figure 10). For arm jump power, only the EXP group had a significant increase ($p = 0.019$) (Figure 11). For arm jump distance, only the EXP group had a significant increase ($p = 0.028$) (Figure 12). For the weighted pull-ups repetitions, only the EXP group had a significant increase ($p = 0.039$) (Figure 13). For the body-weight bench press repetitions, there was no significant increase in repetitions ($p = 0.094$) and no interaction between EXP and CON groups ($p = 0.614$) (Figure 14). For the left handgrip test, there was a trend for an overall increase ($p = 0.082$) but no interaction ($p = 0.665$) (Figure 15). For the right handgrip test, there were no changes following training (Figure 16).

Analyzing the factors that may contribute to the performance differences in post-test arm jump distance between groups, multivariate ANOVA showed that the weighted pull-up and peak power were the only factors significant for the arm jump, $p = 0.001$ and $p = 0.004$, respectively (Table 12).The CON and EXP groups engaged in a similar number of climbing sessions during the 6-week program (11.0 ± 7.7 and 11.6 ±0.9, respectively; $p = 0.838$), while the EXP group performed more resistance training sessions (16.7 ± 0.1 vs 6.1 ± 1.7, $p < 0.001$).

CHAPTER 5

Discussion

Summary of Findings

This study aimed to assess the impact of a climbing-specific physical training program on the physical capacities and climbing performance of novice rock climbers, specifically on upper-body power, upper-body strength, grip strength, and a climbing task. While rock climbing requires total body strength and flexibility, upper-body strength tends to be the focus of most strength training programs (Hermans et al., 2017; Medernach et al., 2015; Phillipe et al., 2019; Phillips et al., 2012; Stein et al., 2019; Stein et al., 2021). The central hypothesis of this study was that a climbing-specific training program organized in a block periodized manner with an emphasis on upper body power training would improve physical fitness specific to climbing and improve performance on a relevant climbing test in novice climbers. This hypothesis was supported as demonstrated by significant improvements in physical performance on climbing-specific strength and power tests from pre- to post-testing in the EXP group but not the CON group: arm-jump speed, power, and distance, and weighted pull-ups. Performance on the climbing test improved in both the EXP group and the CON group to a similar degree; the fact that both groups performed a similar number of climbing sessions during the six-week period likely explains the latter result. Three subordinate hypotheses were in addition to the central hypothesis. First, there would be significant differences in physical performance and climbing-specific performance between advanced and novice climbers, with advanced being greater. This hypothesis was supported as pre-testing demonstrated that the ADV climbing group performed significantly better than both novice groups on all performance tests: right- and left-hand grip strength, arm jump speed, power, and distance, weighted pull-ups, body weight bench press, and the climbing test. This revealed an overall enhanced strength and power profile for the upper body and shoulder girdle among advanced compared to novice climbers. Second, a climbing-specific strength and conditioning program would decrease the difference in physical performance and climbing-specific performance between novice and advanced climbers. This hypothesis was only partially supported as the ADV group's pre-test scores were not significantly greater than the EXP group's post-test scores for arm jump power and for body weight bench press, and the ADV group's scores were not significantly greater than either novice group's post-test scores for left or right grip strength. Third, the experimental group would improve physical performance and climbing-specific performance over the control group. This hypothesis was only partially supported as the EXP group had significant improvements from pre- to post-test, but did not have significant improvement over the CON group's performance.

Comparison of Findings

Anthropometric measurements of the novice groups and the advanced group were consistent with the literature with respect to height and body mass (Balas et al., 2012; Billat et al., 1995; Espana-Romero et al.,2009; Grant et al., 1996; 2009; Hermans et al., 2017; Limonta et al., 2018; Merimer et al., 2000; Stein et al., 2019; Stein et al., 2021). Mean BMI for the subjects in this study (24.3 kg/m^2) was slightly higher than in the arm jump validation study (22.1 kg/m^2) reported by Laffaye et al. (2014). The BMI across the novice, skilled, and elite groups in that arm jump study were consistent, whereas in this study the EXP group's was higher (26.0 kg/m^2) compared to the CON or ADV groups (23.3 kg/m^2 and 23.5 kg/m^2, respectively). Compared to the BMI across the novice subjects in Hermans et al. (2017) (22.5 kg/m^2), the CON group (23.3 kg/m^2) was most similar and the EXP group was higher (26.0 kg/m^2). Arm span to height ratios of 1.01 were consistent with Laffaye et al., 2014, and Laffaye et al., 2016.

Grip strength in the literature has been measured by various apparati from hand grip dynamometers to custom made devices to mimic climbing holds or to measure different aspects of grip or finger strength very specifically. Comparing the results in this study to studies that also used hand grip dynamometry (Balas et al., 2012; Espana-Romero et al.,2009; Laffaye et al., 2016; Macias et al., 2015; Medernach et al., 2015; Merimer et al., 2000), the pre-test findings of the ADV group were comparable with the advanced subjects in studies by Balas et al., 2012; Laffaye et al. 2016; and Medernach et al., 2015. Results from the current study (right hand 55.9 kg and left hand 55.6 kg) were lower than published results by Espana-Romero et al. (2009) (81.6 ± 23.7 kg) and higher than results published by Macias et al., (2015) (right hand 46.15 kg and left hand 43.16 kg). The novice subjects in the CON and EXP groups were consistent with the novice subjects reported in Balas et al., 2012 and Laffaye et al., 2016.

Following the 6-week training program, both novice groups showed a trend in grip improvement ($p = 0.082$) but no significant differences between the groups. Previous published studies on hand/finger strengthening programs have been focused on advanced and elite climbers (Levernier et al., 2019; Medernach et al., 2015), but not novice climbers. Levernier et al. (2019) utilized a 4-week finger training program for advanced and elite French climbers. The finger training program occurred two times per week for about 45 minutes each training session involving three types of grips (slope, half crimp, and full crimp). The results showed no significant difference between the experimental and control groups from pre- to post-test for absolute strength but did show a single significant finding for relative strength on the slope grip. Medernach et al. (2015) tested a 4-week fingerboard training program on highly advanced boulder climbers that included multiple fingerboard exercises performed three times per week. The control group was allowed to climb during the four weeks but not to use the fingerboards.

The authors were able to demonstrate significant increases in grip strength in the experimental group from pre- to post-test but not between the experimental and the control groups. With the relative inexperience of the novice climbers and the low starting grip strength, it is likely that any time spent climbing may have been as effective as participating in a specific finger/grip strengthening program. Compared to the two studies presented, the volume and time to complete the finger training in this study was less than those studies. The present study's program consisted of less than 10 minutes of training each session compared to up to 45 minutes of training in Levernier et al., 2019.

The arm jump test described by Laffaye et al. (2014) has been validated to distinguish between climbing ability (novice, intermediate, advanced, elite) and even type of climbing discipline (boulder vs lead climbing). Compared to the advanced and elite climbers in the referenced study, the advanced climbers' arm jump distance (0.70 m) in the current study was similar as the advanced boulder climbers (0.77 m) and better than the advanced lead climbers (0.61 m). The advanced climbers in this study also weighed more (73.7 kg) than the boulder climbers (67.5 kg) or the lead climbers (68.1 kg). The novice EXP climbers in this study performed the pre-test arm jump as well as the novice climbers referenced by Laffaye et al., (2016) (0.38 m vs 0.37 m, respectively), while the CON group pre-test average was numerically lower (0.28 m). Following the 6-week training, only the EXP group had a significant improvement from pre- to post-test in distance (0.38 m to 0.44 m) and power (1291 W to 1473 W). As the weighted pull-ups were shown to be the important factor contributing to the arm jump performance, only the EXP group had a significant increase in weighted pull-up repetitions, which would contribute to the increase in arm jump performance.

In contrast to the findings of Laffaye et al. (2016), the advanced climbers in this study had more general strength as demonstrated by higher bench press scores. Laffaye reported that the advanced (skilled) climbers were able to perform a 1-RM bench press of 73 kg at 69.9 kg body mass, while the advanced climbers in this study averaged 5 repetitions of bench press at body mass (73.7 kg). The novice group in Laffaye's study averaged a 1-RM bench press of 69.7 kg at 70.5 kg body mass, while the two novice groups averaged at or below 1 repetition at body mass (EXP 74.0 kg, CON 69.4 kg). As the 11.4-kg pull-up is not a commonly reported strength test in the climbing literature, comparisons are difficult to make with current literature. Wood and Swain (2021) reported that Naval Special Operator Lead Climbers averaged 16.2 repetitions on the 11.4-kg pull-up. This is more than the 9.2-repetition average for the advanced climbers in the current study. Of note, the advanced climber group is made up of males and females, where in Wood and Swain (2021) only males were members of that study population. The novice groups performed an average of 1.7 (EXP) and 0.8 repetitions (CON) in the pre-test. Only the EXP group had a significant increase in the post-test (averaging 3.5 repetitions).

Training programs to improve climbers' performance have been developed to address the multiple aspects required to enhance climbers' abilities. Training programs have addressed hand and finger grip strength and endurance (Lervernier et al., 2019; Lopez-Rivera et al., 2019; Medernach et al., 2015; Stein et al., 2019; Stein et al., 2021), core strength (Saeterbakken et al., 2018), or more global climbing-specific training (Hermans et al., 2017; Phillippe et al., 2019).

Finger and hand strengthening training studies have focused on advanced and elite climbers. Stein et al. (2021) studied a 5-week program of either 2 times per week (TG2) or 4 times per week (TG4) finger training. The two programs were volume matched with the same exercises on a campus board. Pre- and post-testing included bouldering performance, a dynamic reach test, isometric pull-ups on two different holds, and a campus board to failure test. They found a significant improvement in bouldering performance for the TG2 group ($p = 0.042$) but not for the other group. The TG4 group had a significant improvement in Rate of Force Development (RFD) ($p = 0.003$) while there was no change in the other group. Medernach et al. (2015) utilized highly advanced climbers to study 4 weeks of finger board training vs 4 weeks of bouldering. They reported that the fingerboard group had a significant increase in grip strength measured by a hand dynamometer, but there was no significant difference in grip strength compared to the bouldering group. In the current study, finger strengthening exercises were included 3 times per week for 6 weeks in the form of fingerboard hangs, campus board training, and finger pinch training. There was a trend in both novice groups combined for grip strength improvement in left hand only ($p = 0.082$) with no difference between EXP and CON. This is perhaps because 6 weeks is too short, but more likely the training stimulus was not enough with only one grip strength exercise per training session.

A literature review revealed only one study that utilized novice climbers to evaluate the effect of strength training programs on climbing performance and physical performance. Hermans et al. (2017) compared two training programs that utilized strength exercises either in a high-resistance, few-repetition (HR-FR) regimen or a low-resistance, high-repetition (LR-HR) regimen, 2 times per week over 10 weeks. Thirty subjects were randomly and equally assigned into the two experimental groups and a control group. Pre- and post-testing were conducted in the same order of the graded wall climbing test (IRCRA rating 8-13), the bent-arm hang for time (climbing-specific), a dead hang for time (climbing-specific), and the 12-RM pull-down test. During the 10-week training course, both experimental groups performed the same exercises, but each in their prescribed repetition and resistance manner. The control group refrained from lifting for the 10 weeks. All subjects were instructed to continue their normal climbing routine. Of the seven exercises in the prescribed program (pull-down, seated bench press, seated shoulder press, seated rowing, biceps curls, forearm press, and forearm curls), all but the biceps curls were performed in a seated position. The biceps curls were not defined as seated or standing. The first four exercises were performed on a machine while the last three utilized free weights. Both experimental groups completed approximately 20 lifting sessions during the 10 weeks. Both experimental groups had decreased their climbing sessions from a required 2 or more per week for study eligibility to 0.7 sessions per week, while the control group averaged 1.5 sessions per week. Post-test results showed only trends for improvement for either experimental group (p = 0.088 and p = 0.090) in the graded wall climbing test, with no change in the control group. Both experimental groups increased their performance on the dead hang, the bent-arm hang, and the 12-RM pull-down, with no difference between these two training groups. The only significant change in the control group was a modest increase in the bent-arm hang. The lack of significant improvement by the training groups during the graded climbing wall test may have been due to their limited climbing practice during the 10-week period and the fact that the strength training did not involve moving their own body weight. The authors noted that many of the novice climbers began the training program with very low relative strength as determined by the seated pull-down exercise. Significant strength improvements in the bent-arm test by all three groups may have been due to improvements over the low relative strength at the start of the study. The selected tests required the climbers to hold their body mass in isometric dependent positions, which contrasts with the exercise selections with which they trained. Also, no hand or finger strengthening exercises were included in the training.

The graded climbing wall tests of Hermans et al. and this study are difficult to compare. Both routes consisted of at least 40 holds (43 in Hermans et al.) and each subject was top roped during the test, but the route used by Hermans et al. started at an IRCRA rating of 9 and increased to 13 whereas this study utilized a route with an IRCRA rating of 6 to 18. A higher rating was needed to identify the ADV climbers for this study. As Hermans et al. only reported the number of holds attained by their subjects instead of giving the IRCRA climbing rating attained actual grade improvement could not be determined. The remaining testing battery, of this study, could not be compared to Hermans et al. as the selected tests for each study differed greatly and offered no similarities.

In contrast to Hermans et al., the current study utilized a 6-week program broken into two 3-week blocks instead of a continuous 10-week program. The current program targeted general strength and finger/grip strength in the first block, and then added speed and power in the second block. The design of this program was to facilitate training in a weightroom as might be found in a typical indoor rock-climbing facility or a military performance training facility. As such, the selection of exercises (body weight or body weight plus exercises, free weights, and assistive/resistive bands) required the subjects to either train in a standing or hanging (dependent) position or perform movements supporting and controlling their own body weight. It also included finger strengthening exercises. The incorporation of speed-based training via jumping pull-ups and velocity pull-ups (derived from the arm jump test) most likely led to the significant increase in arm jump velocity and power in the EXP group. As there was not a dynamic test in the Hermans et al. study, comparisons on speed and power improvements may not be made. Importantly, despite having the same number of subjects per group in both studies and a shorter training period in the current study, there was a significant increase in climbing performance in the current study but only a trend for such improvement in Hermans et al. This may be because the two training groups in the earlier study only averaged 0.7 climbing sessions per week, while the average in the current study was 1.9 per week.

Limitations

As this was designed to be a practical study utilizing a private rock-climbing facility with subjects recruited from the community, limitations from this design were expected to be present. The first limitation was the setting of a private rock-climbing facility instead of a well-controlled laboratory. Especially for testing, but sometimes for assistance/monitoring of training, the schedules of the facility or the number of patrons there required flexibility in scheduling testing or training. This may have affected the efficiency of repeated measurements, though the manner of testing was always consistent. As it worked out for most subjects, pre- and post-testing occurred at the same relative time of day (morning, afternoon, or evening) instead of exactly replicating testing times. This was due to the schedule of the facility, the subject, or (rarely) the investigator.

Another limitation was the extent to which an indoor rock-climbing facility could provide external validity to be replicated in other settings. While the graded route could be replicated within the original facility, it would be very difficult to do so in other facilities based on the walls (vertical or overhung) and the types of holds used. As the route was set up indoors, it may have difficulty transferring to climbing outdoors on natural rock.

A third limitation was the ability for onlookers, not associated with the study at the time, to watch subjects climb and therefore get foreknowledge of the climbing route if they were to later join the study. There was no possibility of hiding the route from the rest of the patrons. A mitigation effort was to talk with any patron who might have interest in the study to keep them from studying or attempting to climb the route to gain advanced knowledge.

A fourth limitation that may have affected some of the outcomes of this study was the variability in physical performance of novice climbers, some of whom had very low starting physical fitness. Also, because of their lack of continuous training history, high variance in their performance on the physical fitness tests may have caused high standard error which may have limited the ability to obtain significant findings. This may have most influenced the weighted pull-up and the arm jump test metrics as subjects would not have been used to performing the test movements.

A final limitation was the recruitment of subjects. The process of recruiting and collecting data was very slow, lasting over 16 months. This was due in part to the small climbing population from which to recruit in the Hampton Roads area. Because this is not an area with natural rock-climbing sites, there is a limited population to engage. After 12 months, only 20 novice subjects had been recruited, and 3 of these dropped from the study. A stipend was then offered for novice subjects to enroll, which yielded 4 new subjects over the next 4 months. Having only 10 subjects in the CON group and 11 in the EXP group meant that changes in performance after training would have to be large and consistent to reach significance. For example, the EXP group had a numerically larger increase in climbing grade after the 6-week training period than the CON group, but this potential difference failed to reach significant. The two groups had a similar number of climbing sessions during the 6-week period, though the variance was more in the CON group than EXP group (SEs of 7.7 and 0.9, respectively). Would a larger n have yielded a significantly greater improvement in climbing performance by the EXP group, or would a longer training period be required regardless of the n? It is possible that increasing both the n and the training period would have failed to achieve a significantly greater climbing performance in the EXP group over the CON group if a parity of climbing session frequency is sufficient to improve climbing performance in novice individuals.

Future Research

Future research recommendations should focus more specifically on more sensitive tests for novices to elucidate strength changes better. Body weight pull-up tests instead of weighted pull-up tests and fingerboard tests vs hand dynamometer tests could be substituted to better capture novice climbers' physical capacity. Finger strength rate of force development should also be investigated to determine if the grip strength training is affecting this important capability. Rate of force development testing would necessitate more advanced testing equipment than was available for this study. Adding a floor to ensure that the novice climbers had a certain number of climbing sessions may be helpful but may also unduly limit the number of available subjects. Making the study a multi-site study may be more helpful in subject recruitment and increase the power of the study by having larger subject groups.

As the testing and training protocols were developed to be used in a non-laboratory setting and be very portable so that they could be brought to the climbers, a second focus of future studies would be to bring the testing and training to the industrial and tactical settings. Fire and rescue first responders, and certain military personnel (special operations) are required to climb either natural or manmade structure. Developing a testing and training protocol for these industries may provide a better understanding of the physical capabilities of the climbers and a method for enhancing climbing performance and safety for them.

A third focus on future research would be to examine the difference in changes in performance in males and females due to training. Elucidating if the program had a larger or smaller effect on either males or females would help practitioners develop specific training programs tailored to the individual. The current study and Hermans et al. (2017) included both males and females, but the n was too low to evaluate their responses to training separately.

A final focus would be on whether upper body power and speed training would improve the climbing ability of novice boulderers. Bouldering involves series of powerful moves that involve strength and power and high contact grip strength. The arm jump test would be a suitable climbing-specific test for bouldering as described by Laffaye et al. (2014) and coupled with a finger rate of force development test may provide the data to provide effective training protocols.

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TABLES

Table 1. Climbing Ability Rating for IRCRA and Other Common Rating Scales.

Climbing Group	IRCRA rating	YDS	French/Sport
Novice (Level 1)	1	5.1	1
	2	5.2	2
	3	5.3	2+
	4	5.4	3-
	5	5.5	3
	6	5.6	3+
	7	5.7	4
	8	5.8	4+
	9	5.9	5
Intermediate (Level 2)	10	5.10a	5+
	11	5.10b	6a
	12	5.10c	6a+
	13	5.10d	6b
	14	5.11a	6b+
	15	5.11b	6c
	16	5.11c	6c+
	17	5.11d	7a
Advanced (Level 3)	18	5.12a	7a+
	19	5.12b	7b
	20	5.12c	7b+
	21	5.12d	7c
	22	5.13a	7c+
	23	5.13b	8a
Elite (Level 4)	24	5.13c	8a+
	25	5.13d	8b
	26	5.14a	8b+
	27	5.14b	8c
Higher Elite (Level 5)	28	5.14c	8c+
	29	5.14d	9a
	30	5.15a	9a+
	31	5.15b	9b
	32	5.15c	9b+

Note. Adapted from Draper et al., 2015, Comparative grading scales, statistical analyses, climber descriptors and ability grouping: International Rock Climbing Research Association position statement. *Sports Technology*, *8*(3–4).

Table 2. Foundation Strength Block

	Day 1	Day 2	Day 3
Wk1	Injury prevention Finger strength campus board 4 x 6 sec. 2-min rest Pull-ups 4x8-12 Bar Dead hang 4 x 30 sec Push-ups 4x20-30	Injury prevention Finger strength finger board 4 x 10 sec. 2-min rest Tempo Pull-ups 3x5 (3sec ↓, 1 sec ↑) Single Arm DB row 3x8 Overhead Press 3x8	Injury prevention Finger strength weight pinch 3 x max time. 2-min rest Inverted row 4x15 Single Arm row 4x8 L sit 3x30 sec
Wk2	Injury prevention Finger strength campus board 5 x 6 sec. 2-min rest Pull-ups 4x10-15 Bar Dead hang 4 x 45 sec Push-ups 4x25-35	Injury prevention Finger strength finger board 5 x 10 sec. 2-min rest Tempo Pull-ups 4x5 (3sec ↓, 1 sec ↑) Single Arm DB row 3x8 Overhead Press 3x6	Injury prevention Finger strength weight pinch 3 x max time. 2-min rest Inverted row 4x15 Single Arm row 4x8 L sit 3 x 35 sec
Wk3	Injury prevention Finger strength campus board 6 x 6 sec. 2 min rest Pull-ups 4 x 12-18 Bar Dead hang 4 x 60 sec Push-ups 4x30-40	Injury prevention Finger strength finger board 6 x 10 sec. 2-min rest Tempo Pull-ups 5x5 (3sec ↓, 1 sec ↑) Single Arm DB row 3x8 Overhead Press 3x5	Injury prevention Finger strength weight pinch 3 x max time. 2-min rest Inverted row 4x15 Single Arm row 4x8 L sit 3 x 40 sec

Table 3. Speed/Power Block

	Day 1	Day 2	Day 3
Wk1	Injury prevention Finger strength campus board ladders. 2-min rest Weighted Pull-ups 4x5-10 Jumping pull-up 4 x 5 Band Resisted Push-ups 4x 20-30	Injury prevention Finger strength finger board 4 x 10 sec. 2-min rest Velocity based Pull-ups 3x5 (at speed ≥ than arm jump) Single Arm DB row 3x8 3-position isometric hold pushups 3x8	Injury prevention Finger strength weight pinch 3 x max time. 2-min rest Inverted row 4x15 Single Arm lock-off 4x10 sec Dips 3x8 Side Planks 3x60 sec
Wk2	Injury prevention Finger strength campus board ladders. 2-min rest Weighted Pull-ups 4x8-12 Jumping pull-up 4x6 Band Resisted Push-ups 4x 25-35	Injury prevention Finger strength finger board 5 x 10 sec. 2-min rest Velocity based Pull-ups 3x6 (at speed ≥ than arm jump) Single Arm DB row 3x8 3-position isometric hold pushups 3x10	Injury prevention Finger strength weight pinch 3 x max time. 2-min rest Inverted row 4x18 Single Arm lock-off 4x10 sec Dips 3x12 Side Planks 3x90 sec
Wk3	Injury prevention Finger strength campus board ladders. 2-min rest Weighted Pull-ups 4x10-15 Jumping pull-up 4x8 Band Resisted Push-ups 4x 30-40	Injury prevention Finger strength finger board 6 x 10 sec. 2-min rest Velocity based Pull-ups 4x5 (at speed ≥ than arm jump) Single Arm DB row 3x8 3-position isometric hold pushups 3x12	Injury prevention Finger strength weight pinch 3 x max time. 2-min rest Inverted row 4x20 Single Arm lock-off 4x10 sec Dips 3x15 Side Planks 3x120 sec

Table 4. Baseline Characteristics

	CON (X ± SE)	EXP (X ± SE)	ADV (X ± SE)
Sex	5 F, 5 M	5 F, 6 M	3 F, 11 M
Age (yr)	28.1 ± 2.5	33.9 ± 2.7*	29.7 ± 2.0
Height (m)	1.73 ± 0.03	1.69 ± 0.04	1.76 ± 0.03
Mass (kg)	69.4 ± 3.1	74.0 ± 3.4	73.7 ± 4.3
BMI (kg/m^2)	23.3 ± 0.9	26.0 ± 0.9*	23.5 ±0.8
Arm Span (m)	1.71 ± 0.02	1.71 ± 0.05	1.77 ± 0.03
Arm Span to Ht ratio	0.99 ± 0.02	1.01 ± 0.04	1.01 ± 0.03

Note. *EXP older than CON $p = 0.049$; *EXP BMI higher than CON $p = 0.044$

Table 5. One-Way ANOVA on Pre-Test Performance Measures

						Post Hoc		95% Confidence Interval Mean Difference	
Dependent Variable	Group	Group	Mean Difference	Std. Error	*p*	t	*p*	Lower Bound	Upper Bound
Grip L Pre Max	ADV	EXP	14.7*	4.61	0.009	2.821	0.010*	3.9	25.4
		CON	16.6*	4.73	0.004	3.370	0.003*	6.4	26.8
Grip R Pre Max	ADV	EXP	12.6*	4.35	0.019	2.653	0.014*	2.8	22.4
		CON	13.9*	4.47	0.011	3.113	0.005*	4.6	23.1
AJ Peak Vel Max	ADV	EXP	1.7*	0.45	0.002	3.348	0.001*	0.7	2.7
		CON	2.0*	0.46	<0.001	3.887	<0.001*	0.5	0.9
AJ Peak Power Pre	ADV	EXP	1270.1*	390.48	0.007	2.866	0.009*	353.4	2186.9
		CON	1527.4*	401.27	0.002	3.325	0.003*	574.7	2480.1
AJ Dist Pre Max	ADV	EXP	0.3*	0.07	<0.001	4.215	<0.001*	0.2	0.5
		CON	0.4*	0.07	<0.001	6.795	<0.001*	0.3	0.5
11.4kg Pull up Pre	ADV	EXP	7.5*	1.73	<0.001	3.805	<0.001*	3.4	11.6
		CON	8.4*	1.78	<0.001	4.221	<0.001*	4.3	12.6
BW Bench Press Pre	ADV	EXP	4.0*	1.56	0.040	2.192	0.039*	0.2	7.8
		CON	4.6*	1.60	0.019	2.461	0.022*	0.7	8.8
IRCRA Grade Pre	ADV	EXP	10.2*	0.22	<0.001	51.048	<0.001*	9.8	10.6
		CON	10.3*	0.23	<0.001	57.626	<0.001*	9.9	10.7

* The mean difference is significant at the 0.05 level.

Table 6. Benjamini-Hochberg Procedure for Pre-Test One-Way ANOVA

	Dependent Variable	p-value	Rank	(i/m)*q
ADV compared to EXP	Arm Jump Distance (m)	<0.001*	1	0.00625
	11.4-kg Pull-Up (reps)	<0.001*	2	0.0125
	IRCRA Grade	<0.001*	3	0.01875
	Arm Jump Velocity (m/s)	0.002*	4	0.025
	Arm Jump Power (W)	0.007*	5	0.03125
	Left Hand Grip Strength (kg)	0.009*	6	0.0375
	Right Hand Grip Strength (kg)	0.019*	7	0.04375
	Body Weight Bench Press (reps)	0.040*	8	0.05
ADV compared to CON	Arm Jump Velocity (m/s)	<0.001*	1	0.00625
	Arm Jump Distance (m)	<0.001*	2	0.0125
	11.4-kg Pull-Up (reps)	<0.001*	3	0.01875
	IRCRA Grade	<0.001*	4	0.025
	Arm Jump Power (W)	0.002*	5	0.03125
	Left Hand Grip Strength (kg)	0.004*	6	0.0375
	Right Hand Grip Strength (kg)	0.011*	7	0.04375
	Body Weight Bench Press (reps)	0.019*	8	0.05

* The mean difference is significant at the 0.05 level.

Table 7. Multivariate ANOVA Contribution to Distance in Arm Jump Pre-Test

Effect		Value	F	Hypothesis df	Error df	*p*
Intercept	Pillai's Trace	0.856	51.328	3	26	<0.001
	Wilks' Lambda	0.144	51.328	3	26	<0.001
	Hotelling's Trace	5.922	51.328	3	26	<0.001
	Roy's Largest Root	5.922	51.328	3	26	<0.001
@11.4-kg Pull-up Pre	Pillai's Trace	0.554	10.746	3	26	<0.001
	Wilks' Lambda	0.446	10.746	3	26	<0.001
	Hotelling's Trace	1.24	10.746	3	26	<0.001
	Roy's Largest Root	1.24	10.746	3	26	<0.001

a Design: Intercept + @11.4-kg Pull-up Pre + AJ Peak Vel + AJ Peak Power Pre + AJ Rel Peak Power + Cohort

Table 8. One-Way ANOVA on Post-Test Performance Measures

Dependent Variable	Group	Group	Mean Difference	Std. Error	*p*	Post Hoc t	Post Hoc *p*	95% Confidence Interval Mean Difference Lower Bound	95% Confidence Interval Mean Difference Upper Bound
Grip Left Post	ADV	EXP	12.0	5.31	0.076	2.145	0.043*	0.4	23.6
	ADV	CON	12.3	5.46	0.078	2.239	0.036*	0.9	23.6
	EXP	CON	0.3	5.76	0.999	0.046	0.964	-10.9	11.4
Grip Right Post	ADV	EXP	11.2	4.94	0.075	2.255	0.034*	0.9	21.5
	ADV	CON	11.6	5.07	0.071	2.293	0.032*	1.1	22.2
	EXP	CON	0.4	5.35	0.996	0.08	0.937	-10.7	11.6
Arm Jump Peak Velocity	ADV	EXP	1.3*	0.45	0.022*	2.482	0.021*	0.2	2.3
	ADV	CON	1.8*	0.46	0.001*	3.633	0.001*	0.8	2.8
	EXP	CON	0.5	0.48	0.538	1.521	0.145	-0.2	1.2
Arm Jump Peak Power	ADV	EXP	952.0*	371.08	0.039*	2.279	0.032*	88.0	1816.0
	ADV	CON	1325.5*	381.32	0.004*	3.11	0.005*	441.7	2209.4
	EXP	CON	373.5	402.41	0.627	1.489	0.153	-151.4	898.4
Arm Jump Distance Post	ADV	EXP	0.3*	0.07	0.003*	3.416	0.002*	0.1	0.4
	ADV	CON	0.4*	0.07	<0.001*	5.531	<0.001*	0.2	2115.3
	EXP	CON	0.1	0.08	0.306	1.459	0.161	-0.1	0.3
11.4-kg Pull-Up Post	ADV	EXP	5.8*	1.94	0.015*	2.675	0.014*	1.3	10.2
	ADV	CON	7.9*	2.00	0.001*	3.808	<0.001*	3.6	0.5
	EXP	CON	2.2	2.11	0.569	1.287	0.213	-1.4	5.7

	ADV	EXP	3.6	1.62	0.079	1.946	0.064	-0.2	7.5
Bench Press Post	ADV	CON	4.4*	1.66	0.033*	2.318	0.030*	0.5	12.2
	EXP	CON	0.8	1.76	0.901	0.868	0.396	-1.1	2.6
	ADV	EXP	7.2*	1.03	<0.001*	6.988	<0.001*	5.1	9.3
IRCRA Grade Post	ADV	CON	8.4*	1.06	<0.001*	12.452	<0.001*	7.0	8.3
	EXP	CON	1.2	1.11	0.525	0.843	0.410	-1.8	4.2

* The mean difference is significant at the 0.05 level.

Table 9. Benjamini-Hochberg Procedure for Post-Test One-way ANOVA

	Dependent Variable	p-value	Rank	(i/m)*q
ADV compared to EXP	IRCRA Grade	0.001*	1	0.00625
	Arm Jump Distance (m)	0.003*	2	0.0125
	11.4-kg Pull-Up (reps)	0.015*	3	0.01875
	Arm Jump Peak Velocity (m/s)	0.022*	4	0.025
	Arm Jump Power (W)	0.039	5	0.03125
	Right Hand Grip Strength (kg)	0.075	6	0.0375
	Left Hand Grip Strength (kg)	0.076	7	0.04375
	Body Weight Bench Press (reps)	0.079	8	0.05
ADV compared to CON	Arm Jump Peak Velocity (m/s)	<0.001*	1	0.00625
	Arm Jump Distance (m)	<0.001*	2	0.0125
	11.4-kg Pull-Up (reps)	<0.001*	3	0.01875
	IRCRA Grade	<0.001*	4	0.025
	Arm Jump Power (W)	0.004*	5	0.03125
	Body Weight Bench Press (reps)	0.033*	6	0.0375
	Right Hand Grip Strength (kg)	0.071	7	0.04375
	Left Hand Grip Strength (kg)	0.078	8	0.05

* The mean difference is significant at the 0.05 level.

Table 10. Two-Way ANOVA of Pre- to Post-Test Performance Measures

		ANOVA		T-test CON		T-test EXP	
		F	*p*	t	*p*	t	*p*
Left Hand Grip	Between groups	0.065	0.801	2.262	0.119	2.228	0.368
	Within trials	3.302	0.085				
	Interaction	0.194	0.665				
Right Hand Grip	Between groups	0.038	0.848	2.262	0.382	2.228	0.555
	Within trials	1.170	0.293				
	Interaction	0.072	0.792				
Arm Jump Peak Velocity	Between groups	1.634	0.217	2.262	0.311	2.228	0.024*
	Within trials	8.187	0.010*				
	Interaction	3.172	0.091				
Arm Jump Peak Power	Between groups	1.772	0.199	2.262	0.097	2.228	0.019*
	Within trials	11.043	0.004*				
	Interaction	2.318	0.144				
Arm Jump Peak Distance	Between groups	2.057	0.168	2.262	0.120	2.228	0.028*
	Within trials	9.344	0.006*				
	Interaction	0.366	0.552				
11.4-Kg Pull-Up	Between groups	1.273	0.273	2.262	0.138	2.228	0.039*
	Within trials	7.815	0.012*				
	Interaction	2.248	0.150				
Body Weight Bench Press	Between groups	0.824	0.375	2.262	0.443	2.228	0.104
	Within trials	3.210	0.089				
	Interaction	0.263	0.614				
IRCRA Grade	Between groups	0.638	0.434	2.262	0.018*	2.228	0.016*
	Within trials	15.593	<0.001*				
	Interaction	0.768	0.392				

* The mean difference is significant at the 0.05 level.

Table 11. Benjamini-Hochberg Procedure for Post-Test Two-Way ANOVA

	Dependent Variable	p-value	Rank	(i/m)*q
EXP	IRCRA Grade	<0.001*	1	0.00625
	Arm Jump Power (W)	0.004*	2	0.0125
	Arm Jump Distance (m)	0.006*	3	0.01875
	Arm Jump Peak Velocity (m/s)	0.010*	4	0.025
	11.4-kg Pull-Up (reps)	0.012*	5	0.03125
	Left Hand Grip Strength (kg)	0.085	6	0.0375
	Body Weight Bench Press (reps)	0.089	7	0.04375
	Right Hand Grip Strength (kg)	0.293	8	0.05

* The mean difference is significant at the 0.05 level.

Table 12. Multivariate ANOVA Contribution to Distance in Arm Jump Post-Test

Source	Dependent Variable	Sum of Squares	df	Mean Square	F	*p*
Intercept	Cohort	86.403	1	86.403	336.272	< 0.001
	11.4-kg Pull-Up Post	1051.565	1	1051.565	137.037	< 0.001
	AJ Peak Vel Post Max	200.448	1	200.448	195.906	< 0.001
	AJ Peak Power Post Max	109983573	1	109983572.9	337.006	< 0.001
	AJ Rel Peak Power Post	19979.15	1	19979.15	203.367	< 0.001
Arm Jump Distance Post	Cohort	20.46	22	0.93	3.619	0.012
	11.4-kg Pull-Up Post	1064.202	22	48.373	6.304	0.001
	AJ Peak Vel Post Max	47.511	22	2.16	2.111	0.091
	AJ Peak Power Post Max	34680897	22	1576404.4	4.83	0.004
	AJ Rel Peak Power Post	5269.51	22	239.523	2.438	0.056

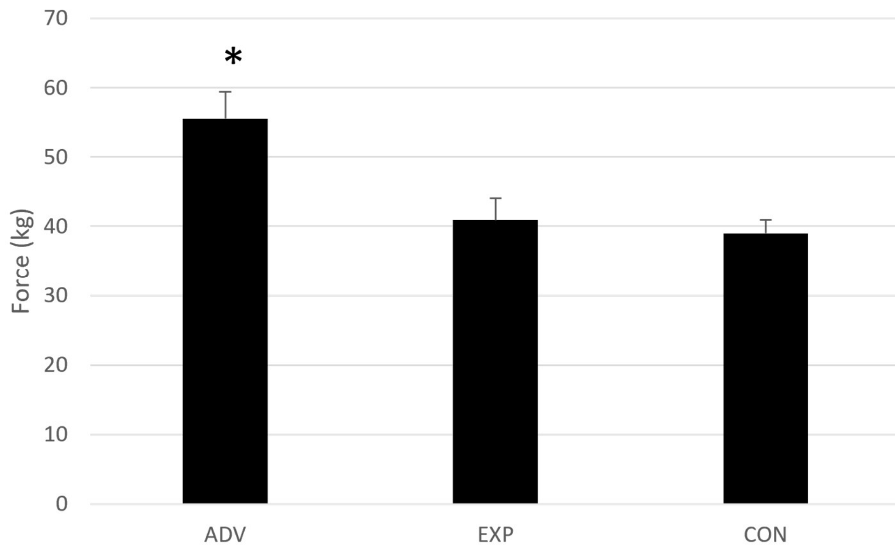
* The mean difference is significant at the 0.05 level.

FIGURES

Figure 1. Arm Jump Apparatus

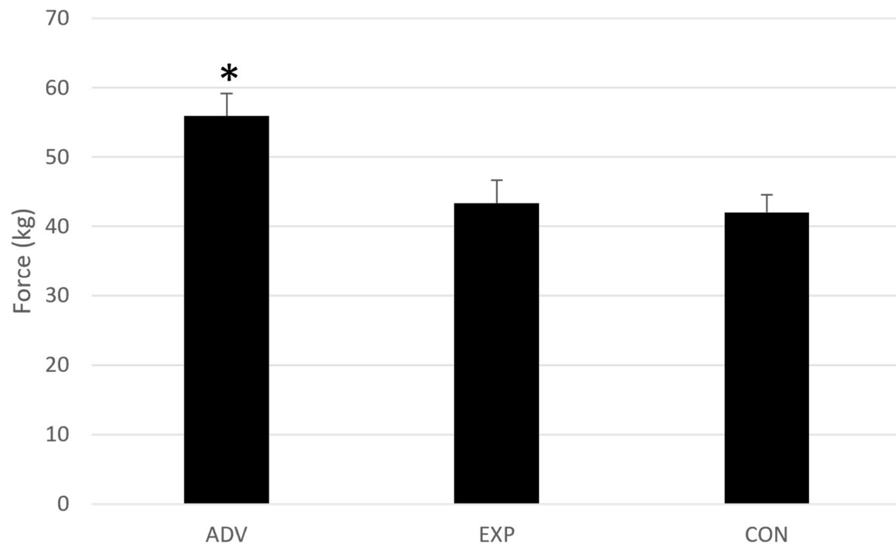
Note. From Laffaye et al., 2014.

Figure 2. Pre-Test Left Hand Grip Strength



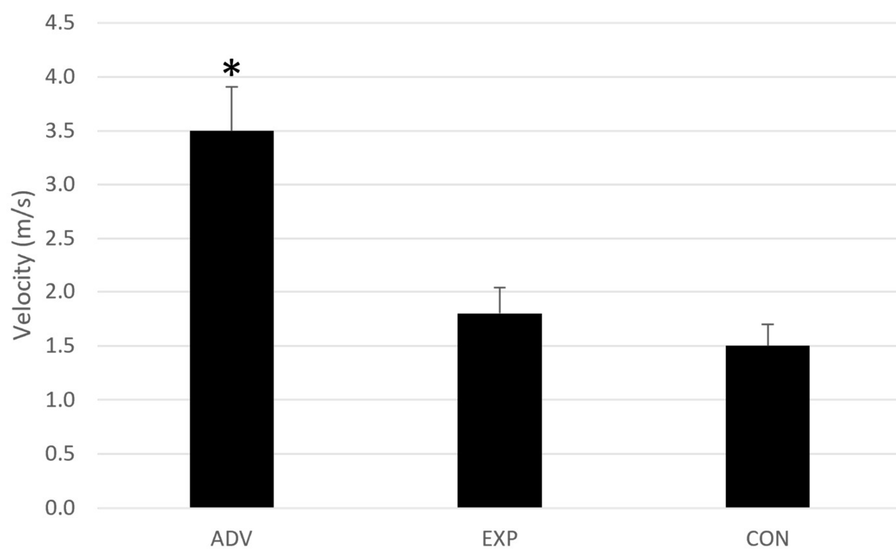
*ADV group significantly greater than EXP and CON (p = 0.010 and p = 0.003, respectively)

Figure 3. Pre-Test Right Hand Grip Strength



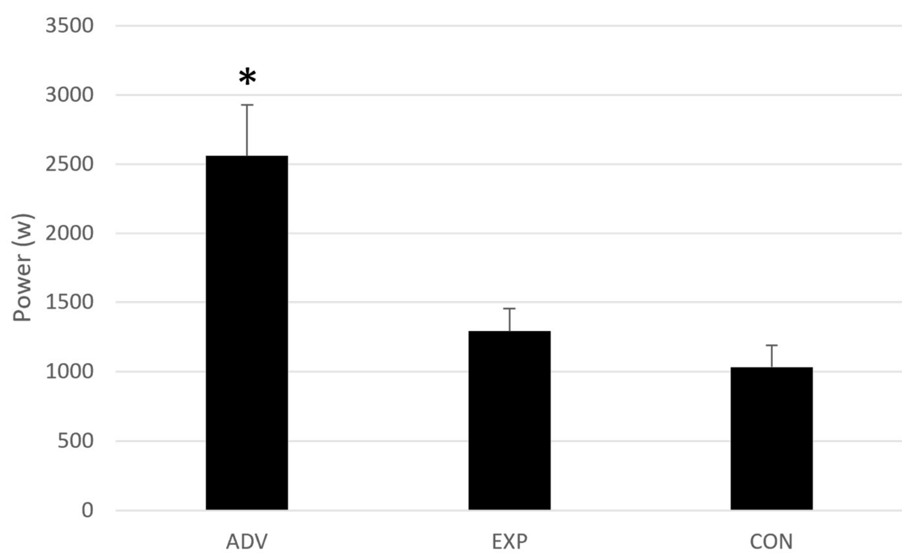
*ADV group significantly greater than EXP and CON ($p = 0.014$ and $p = 0.005$, respectively)

Figure 4. Pre-Test Arm Jump Velocity



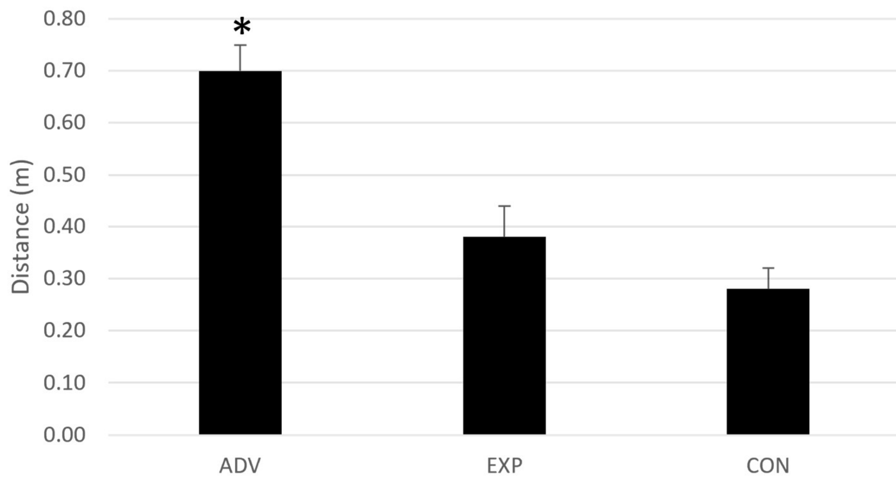
*ADV group significantly different than EXP and CON ($p = 0.003$ and $p < 0.001$, respectively)

Figure 5. Pre-Test Arm Jump Power



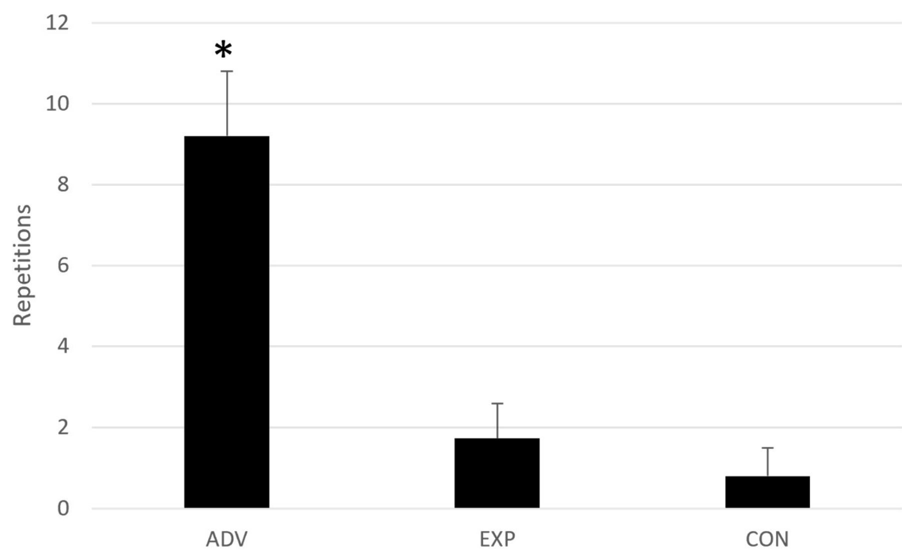
*ADV group significantly greater than EXP and CON ($p = 0.009$ and $p = 0.003$, respectively)

Figure 6. Pre-Test Arm Jump Distance



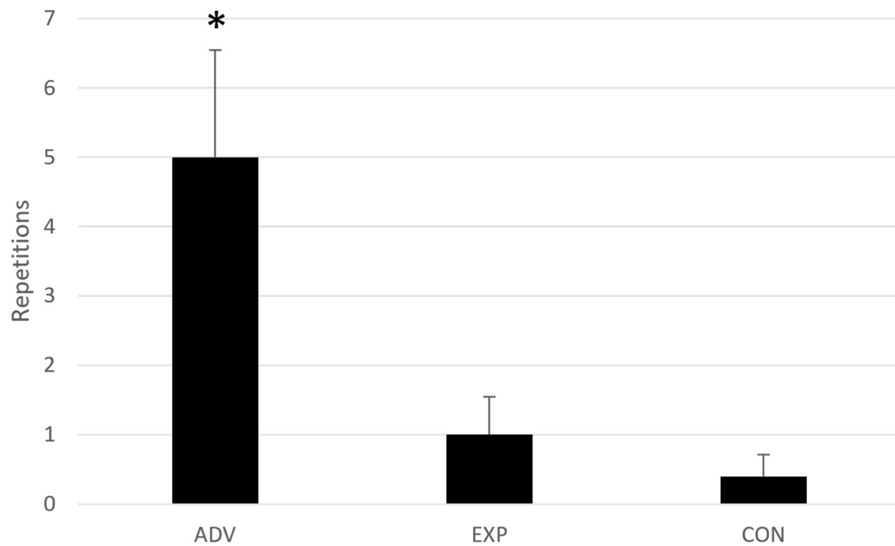
*ADV group significantly greater than EXP and CON ($p < 0.001$)

Figure 7. Pre-Test Weighted Pull-Ups



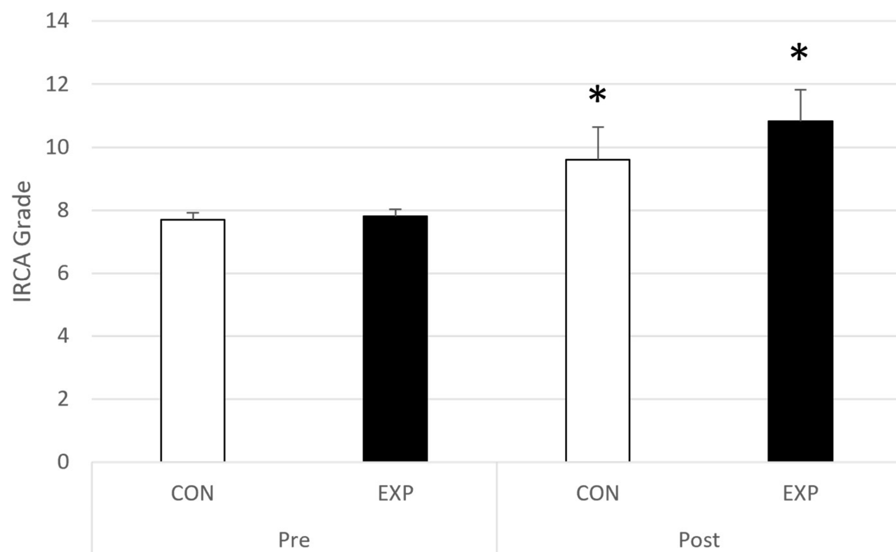
*ADV group significantly greater than EXP and CON ($p < 0.001$)

Figure 8. Pre-Test Body-Weight Bench Press



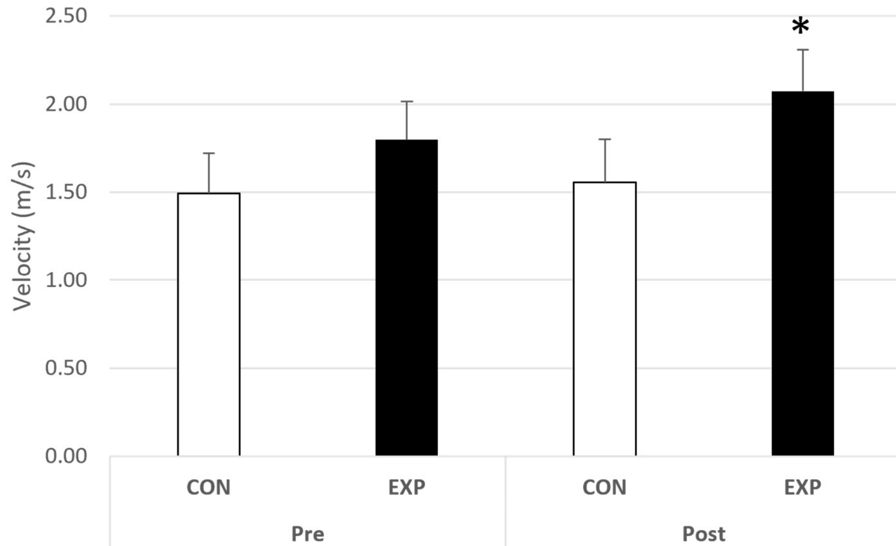
*ADV group significantly greater than EXP and CON (p = 0.039 and p = 0.022, respectively)

Figure 9. IRCRA Grade Pre- and Post-Test



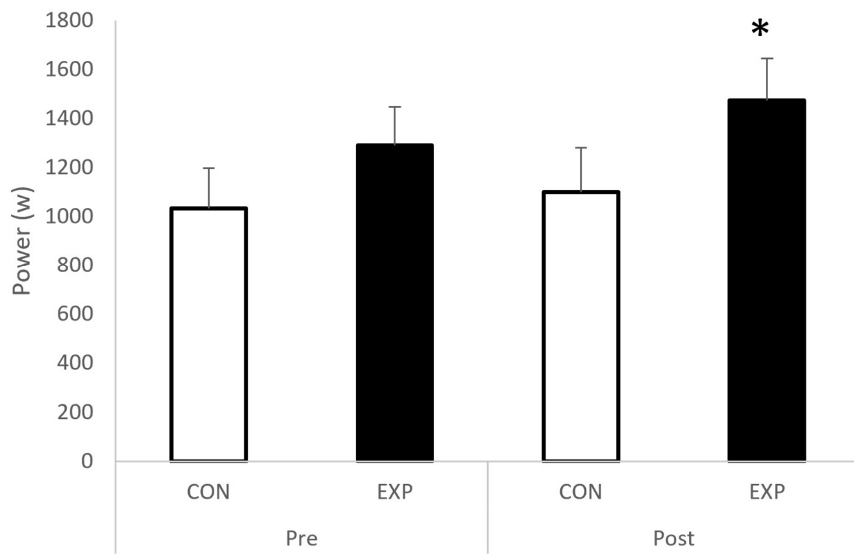
* Both groups significantly increased from pre- to post-test (EXP $p = 0.016$; CON $p = 0.018$) but no difference between groups ($p = 0.392$).

Figure 10. Arm Jump Velocity Pre- and Post-Test



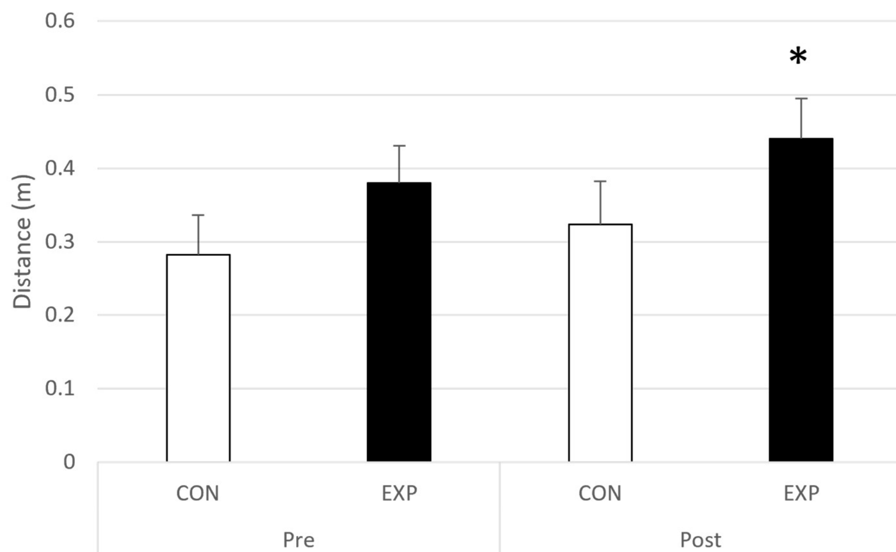
*EXP group increased from pre- to post-test (p = 0.024).

Figure 11. Arm Jump Power Pre- and Post-Test



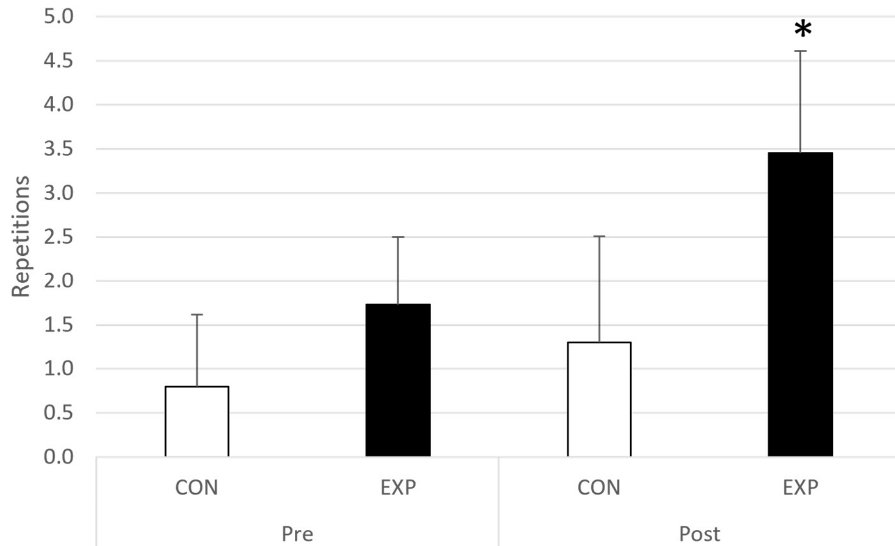
*EXP group increased from pre- to post-test (*p* = 0.019).

Figure 12. Arm Jump Distance Pre- and Post-Test



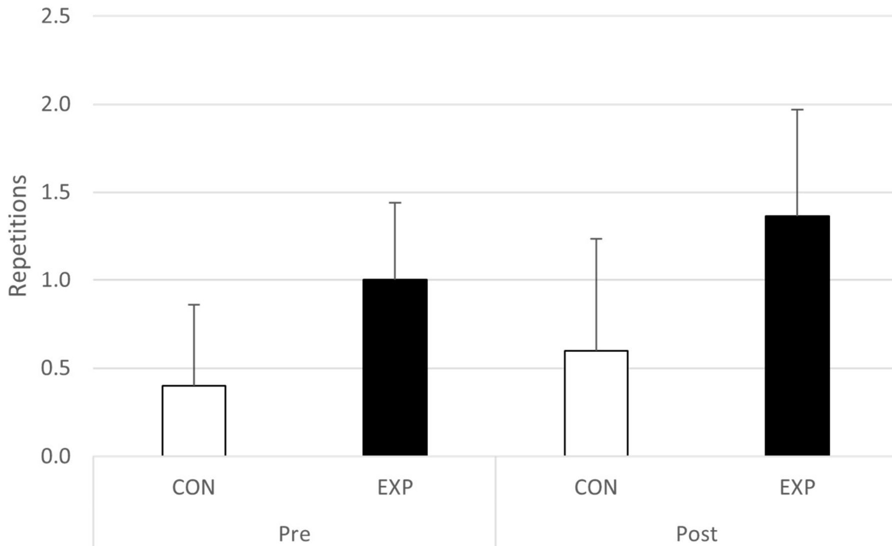
*EXP group significant increase from pre-test to post-test (p = 0.028).

Figure 13. Weighted Pull-Ups Pre- and Post-Test



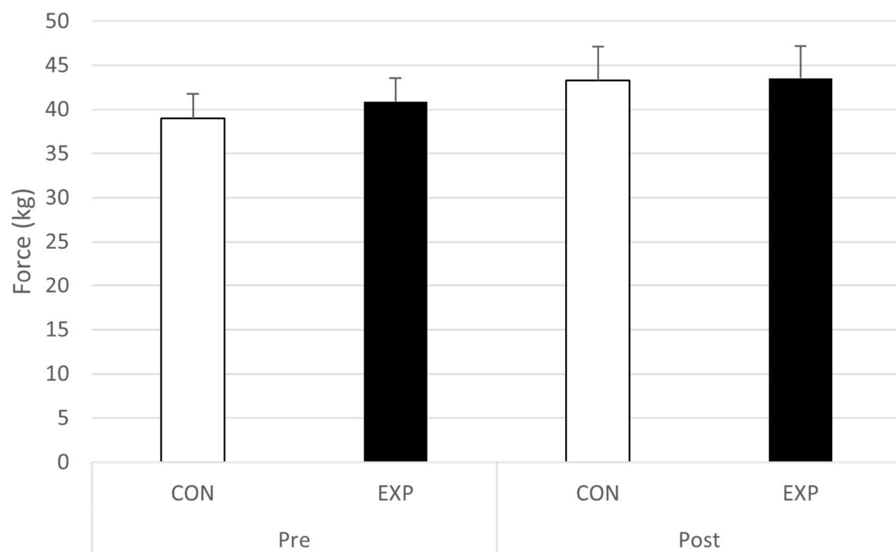
*EXP group significant increase from pre-test to post-test ($p = 0.039$).

Figure 14. Body-Weight Bench Press Pre- and Post-Test



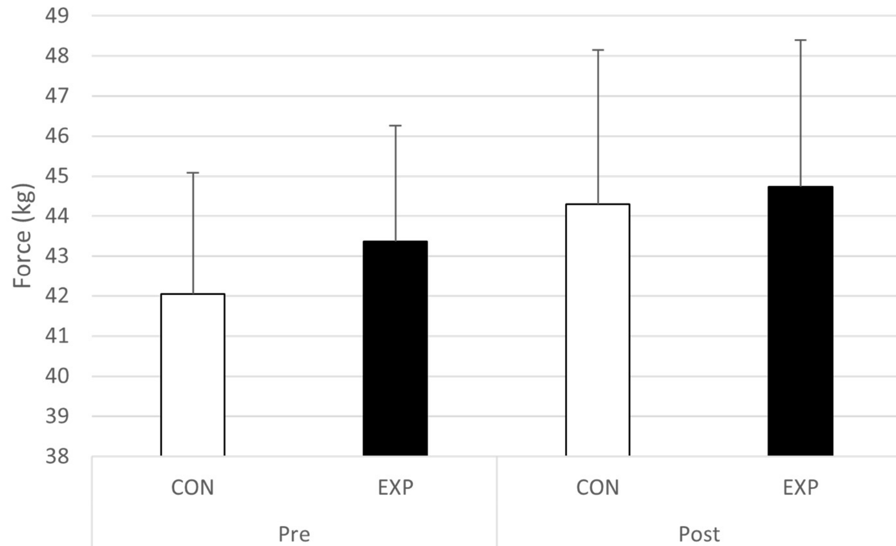
No significant differences between pre- to post-test between groups.

Figure 15. Left Hand Grip Pre- and Post-Test



No significant differences between pre- to post-test between groups.

Figure 16. Right Hand Grip Pre- and Post-Test



No significant differences between pre- to post-test between groups.

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Publications

Abt, J.P., Oliver, J.M., Nagai, T., Sell, T.T., Lovalekar, M.T., Beals, K., Wood, D.E., & Lephart, S. M. (2016). Block-periodized training improves physiological and tactically relevant performance in Naval Special Warfare operators. *Journal of Strength Conditioning Research,* 30: 39–52.

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