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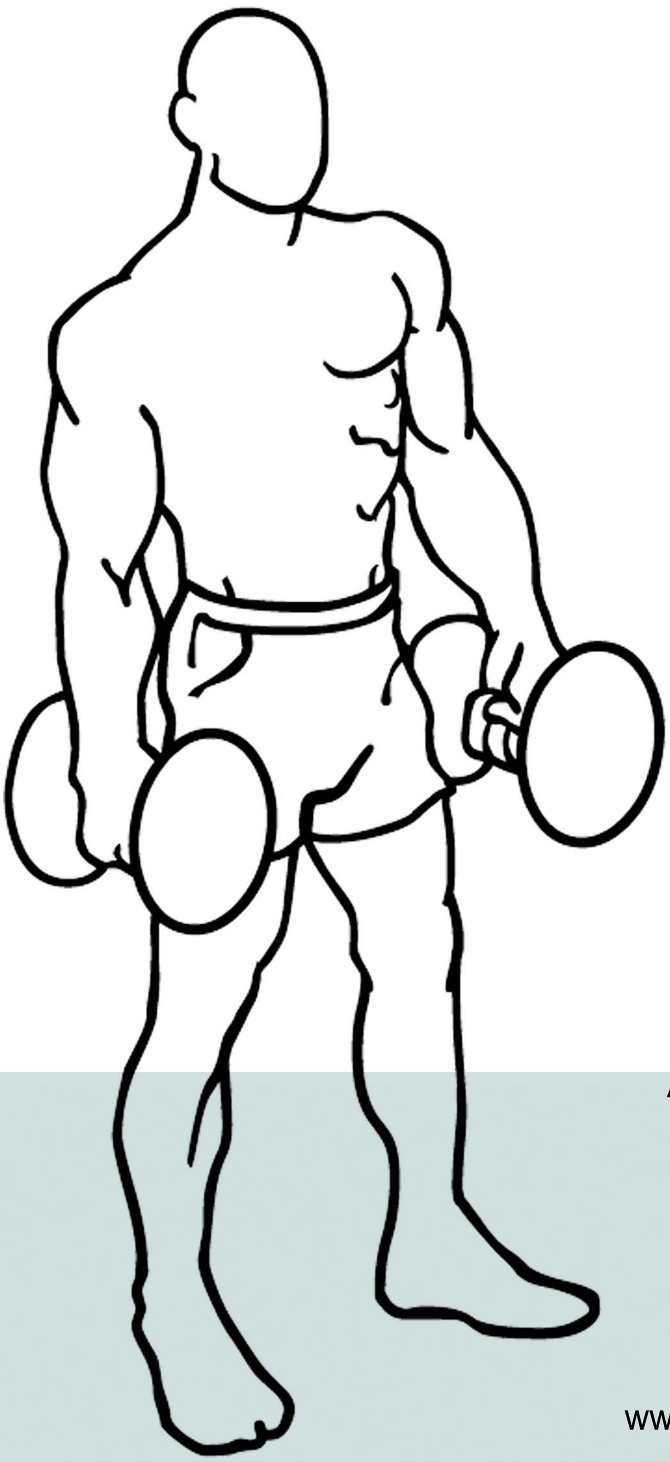

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Review

A Review of Martial Arts and Bone Health Status in Young and Older Population

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ABSTRACT

It is well known that mechanical loading imposed on a bone is important for bone development. Therefore, one of the most effective osteoporosis prevention strategies is by adopting weight-bearing physical activity. Martial arts such as judo, silat, karate, taekwondo and kickboxing are getting popular in recent years. It is generally known that bone's optimum response and adaptation to an applied load or strain during exercise are dependent on many factors, such as characteristics of the strain, i.e. static *versus* dynamic strain, strain magnitude, strain rate, strain frequency or duration, and distribution of the strain stimulus. It has been reported that martial arts are physical activities which can impose loads on the bone with their high and unusual distributed strains and subsequently increase bone health status of an individual. This article discusses the relationship between bone health and physical activity, types and characteristics of martial arts, and effects of various types of martial arts on bone health in young and older population.

Keywords
Bone; Physical activity; Martial arts.

BONE HEALTH AND PHYSICAL ACTIVITY

Bone is a metabolically active tissue that undergoes a continuous remodelling throughout its life cycle. The endogenic factors which can influence the accumulation of bone mineral in humans are heredity, ethnicity, gender and endocrine status. Meanwhile, the exogenic factors are nutrition and physical activity.[1,2]

Peak bone mass is attained during the second and third decades of life. Sports participation can lead to adaptive changes that improve bone architecture through increased density and enhanced geometric properties.[3] Hara et al[4] suggested that physical activities are the strongest determinant of high peak bone mass in young adults at pre-puberty and puberty. Furthermore, physical activity begun during the teenage years could also be useful for preventing osteoporosis and improving future quality of life of an individual.

It has been reported that weight-bearing sport activities are associated with a high bone mass in the lumbar spine, hip, femur, proximal tibia, and calcaneus.[5,6] It has also been reported that different types of physical activity create different strain demands on the skeletal bones.[6,7] In addition, Lanyon[8] mentioned that mechanical loading imposes on a specific bone site should produce high strains in unusual patterns during short periods with high repetition for obtaining the greatest osteogenic effect.

According to Haapasalo et al[9] loading exercises enhance bone mass, and it is necessary to have more weight on bones than common weights that occur in daily life. The osteogenic responses on the skeleton are specific to the region of mechanical stress, and the responses can be triggered by exercises.Exercise can increase the rate of osteogenesis and subsequently increase bone mineral density (BMD).

Robling et al[10] stated that optimum response and adaptation of bone to an applied load or strain during exercise depends on many factors, which are characteristics of the strain, i.e. static *versus* dynamic strain, strain magnitude, strain rate, strain frequency or duration, and distribution of the strain stimulus. In addition, high impact dynamic loading activities, which involve high bone strain magnitude, rate, and with short duration of repeated bone loading and/or versatile strain distribution can provide large osteogenic stimulus in humans.[6] Uneven distribution of the strain seems to have a higher potential for increasing osteogenesis.[5,11] Moreover, the adaptive response of bone decreases after a few loading cycles.[12]

INTRODUCTION OF MARTIAL ARTS

In ancient times, martial arts were practiced for self-defence, however, nowadays they are practiced for improvement in physical fitness level as well.[13] According to Bu et al[14], there are about 200 distinct disciplines of martial arts, and different facets of disciplines make them unique and special. All these disciplines share a common goal, i.e. to defend oneself from physical threat. Nowadays, martial arts are studied for various reasons, including fitness and self-defence enhancement, mental discipline, character development, and as a complementary or alternative therapy for some medical conditions.[15] Martial arts is popular in many cohorts in terms of health promotion. For example, elderly persons can gain health benefits by performing tai chi exercise.[16,17]

Traditional styles of martial arts can be classified as either "soft" or "hard". The 'soft' martial arts are based on redirecting the opponent's energy or attack and less powerful in punching and kicking actions, whereas the 'hard' martial arts are based on using blocks and punches that can crush bones or body parts of an enemy. Hard martial arts deliver significantly more powerful strikes and rigid stances.[18]

The term martial art is often used to describe many of the combat arts that have been developed in eastern cultures, and most of the martial arts practiced in the United States are those that originated or evolved in China, Korea, and Japan.[14] The martial arts of 'wushu' which originated in China include kungfu and tai chi chuan. Japanese martial arts include aikido, karate, sumo and judo. Taekwondo which was developed in Korea is a popular martial art nowadays, perhaps the most prevalent of the martial arts in the United States. Many other forms of martial arts have evolved throughout the world, such as silat (Malaysia), Muay Thai (Thailand), Pencak silat (Indonesia), Bando (Burma), Copoiera (Brazil) and Kahli (Philippines).[14]

EFFECTS OF MARTIAL ARTS ON BONE HEALTH

In a study conducted by Shin et al[19] which determined the effects of taekwondo training on the bone health status of high school female students with aged 13 to 17-years old in Korea, it was found that the average BMD in the taekwondo group was significantly greater than the sedentary control group for all lumbar spine regions. It was approximately 15% higher in the lumbar spine and 17% higher in the femoral neck, which identified that taekwondo could improve bone health. Therefore, the authors mentioned that intermittent taekwondo activity as weight-bearing exercise should be recommended to increase BMD in adolescent females during growth. In addition, the authors also mentioned that their study findings support the concept that high strain rates and high peak stresses are more effective in enhancing bone formation than a large number of low-force repetitions.

Kim et al[20] carried out a study to determine the effects of judo practice on the bone health status of high school male students with mean age of 17.2-years old in Korea. In this previous study, the boys who had engaged in judo practice had greater BMD in their lumbar, femur, and wrist regions when compared with their non-active subjects. According to the results of this study, the BMD was approximately 22.7% higher in the lumbar spine, 24.5% higher in the femur and 18.3% higher in the forearm of judo players when compared to sedentary control group. The authors mentioned that judo involves both high intensity and high strain rates, which strongly stimulate bone formation. Specifically, unusual strain distribution and versatile loading patterns, both are involved in the practice of judo for promoting bone mineralization with greater effects compared to exercises involve regular loading patterns. Therefore, the authors suggested that judo activity is strongly recommended to improve bone health and prevent osteopenia in young Korean males.

A previous study has been carried out by Ito et al[21] to investigate the relationship between martial art practice of judo, karate and kungfu with bone mineral density in adolescents with age between 11 to 17-years-old in both sexes. Their study showed that adolescents engaged in judo practice exhibited higher values of BMD in the arms compared to karate and kungfu participants. The authors also mentioned that muscle mass and biological maturation have been verified as important factors in bone mass and geometry gain.

A recent study conducted by Norsuriani and Ooi[22] examined bone health status of Malay adolescent female silat and taekwondo practitioners with age ranged from 15 to 19-years-old. They found that there were no significant differences in quantitative ultrasound measurement of the bone speed of sound (SOS) of dominant and non-dominant arms and legs of young females among sedentary control, silat and taekwondo groups. In this study, the average age of the participants was 17-years-old, all the participants were Malay females, and their average duration of involvement in martial arts was 2 to 3-years. It is speculated that differences in gender, age, ethnicity, duration of involvement in martial art training may have caused the inconsistent results of this study compared to the aforementioned previous studies.

Drozdzowska et al[23] examined skeletal status assessed by quantitative ultrasound measurement (QUS) at the hand phalanges in 226 karate male practitioners between 7 to 61-years of age, who had been training karate for at least 6-months. The results showed that there were significant differences in bone mineral density of karate athletes compared with control subjects. The authors mentioned that longer duration, higher frequency, and early involvement in physical training positively influenced the skeletal status. They concluded that karate is a sport which can elicit a positive influence on the skeletal status, with the most significant benefits occurring in adults.

Andreoli et al[24] investigated the effects of different sports including martial arts on bone density and muscle mass in highly trained athletes. In their study, participants consisted of judo (n=21), karate (n=14), and water polo (n=24) men athletes with age ranged between 18 to 25-years-old who competed at national and international levels, and age-matched non-athletic individuals were served as the control group. Their study found that athletes had significantly greater BMD than the non-athletes of similar age and in particular, the judo athletes, who practicing a high-intensity weight-bearing sport, had higher values of BMD compared to other athletes. Therefore, the authors highlighted that physical activity appears to have a beneficial effect on bone mass, with greater mechanical loading appears to result in a greater bone mass, and these appeared to be a site-specific skeletal response to the type of loading at each BMD site.

Agostinete et al[25] investigated the effect of karate, judo, soccer and basketball on bone mineral density (BMD) accrual among male adolescents with age ranged from 11 to 17-years-old. In this previous study, it was observed that karate and judo groups exhibited higher BMD than soccer, basketball and control groups. Their findings are consistent with results of previous studies[26,27] which showed that impact sports could enhance bone health among adolescents. The authors mentioned that it is an indicator of responsive loaded sites to the significant amount of mechanical loads induced by martial arts training. The authors also mentioned that during punching, kicking, blocking and striking in martial arts, loading bones are under tensile, compressive, shear, bending, and torsional stress, which produces high strain stimulus for eliciting beneficial effects on bone.

A study was conducted by Platen et al[28] to determine bone mineral density in top-level male athletes of different sports, i.e. athletics, cycling, team sport, judo and wrestling. The participants of this study aged between 18 to 31-years. Among 173 athletes participants, 104 were athletes of runners (n=21), cyclists(n=12), triathletes (n=18), heavy athletes such as judo and wrestling (n=28), and team sport athletes (handball, soccer, basketball, volleyball, n=25); 44 were not specifically trained sport students and 25 were untrained controls. This previous study found that at most sites, BMD was highest in heavy athletes (judo and wrestling) followed by athletes in team sports and sports students, and lowest in cyclists and untrained controls. An explanation for these results is that the strain imposed on bone is mainly determined by mechanical forces, and dynamic forces depend on the body mass and acceleration. In judo and wrestling, movements correspond to high maximal muscular strength and power. Besides forces induced by muscular activation, high accelerations and therefore high forces, as well as varied patterns of strain, occur when falling in judo and wrestling. Furthermore, special strength training with heavy weights is a typical and regular training method in these sports. Therefore, high bone formation rate can be expected by involvement in judo and wrestling.

Soo bahk do (SBD; also known as tang soo do) emphasises a combination of hard styles of karate and tae kwon do with the soft style of the Chinese martial arts. Their system of action and the characteristic use of bare hands and feet as striking weapons are different from other martial art systems. A study carried out by Douris et al[29] examined fitness levels of middle-aged martial art practitioners in both genders from 40 to 60-years of age. The study found that the SBD practitioners were higher in bone health status compared to sedentary participants. The authors mentioned that SBD can be considered an excellent form of exercise for the promotion of fitness in middle-aged population.

Ving T sun (VT) is a traditional Chinese martial art that has the potential to be developed into a new form of health-maintenance exercise to prevent bone loss in the elderly. Fong et al[30] compared bone strength, lower limb muscular strength, functional balance performance, and balance self-efficacy between VT martial art practitioners and non-practitioners with mean age of 62.7- years-old in both sexes. In their study, it was found those VT-trained older adults had the significantly higher bone strength than the control group. VT training includes many striking movements using the forearms, for example, sandbag workouts, sticking-hand exercises, and wooden dummy training, and therefore the authors concluded that these movements repetitively load the forearm bones including the radius with high impact forces, resulting in remodeling and strengthening of these bones to withstand the external loads or stress.

Tai Chi is a traditional Chinese mind-body exercise and benefits on health outcome, particularly middle-aged and elderly people. A study conducted by Hui et al[31] which determined the effects of Tai chi on bone mineral density (BMD) in both genders of Chinese adults with aged from 36 to 60-years-old. The study found that there was no significant change in BMD of both groups, i.e. Tai Chi and control groups. These authors concluded that short-term Tai Chi exercise, e.g., 12-weeks may not provide sufficient training stimulation in improving bone health, and may can only be acted as a protective factor for bone loss in older population.

CONCLUSION

Previously published research studies on martial arts mentioned in this article provide evidence that involvement in training and competition of martial arts such as taekwondo, judo, karate, wrestling, soo bahk do, Ving T sun and Tai Chi could elicit beneficial effects on bone health in young and older population. Thus, it can be concluded that engagement in martial arts is one of the effective ways to enhance bone health.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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Opinion

Opioids and Athletes: A Growing Problem and a Deadly Combination

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The use and abuse of opioids has become a public health issue in the United States and is identified as especially problematic among populations that are prone to high levels of pain like cancer patients and those who have undergone surgery as well as those who more frequently experience injuries and are prescribed narcotic pain relievers, such as athletes.[1] In fact, while existing research tends to support that participation in sports works for many young athletes to keep them away from drugs, the inherent risk of injury that is associated with sports makes them more vulnerable than their non-athletic peers to being prescribed an opioid pain medication during their athletic career.[2] In an earlier study by Veliz, et al the researchers established that young people who participated in youth sports during high school were more likely than those who did not to experience a lifetime problem of medical prescription opioid use as well as diversion of opiate medications to others. This is critical information when considering that as much as 20% of student athletes sustained injuries during interscholastic sports events with just short of 50% of those injured requiring surgery and the consequent prescription of opioid pain relievers.[2] Even more, it supports the notion of athletes who typically pride themselves in pursuing proper training and leading healthy lifestyles ultimately using heroin and other opioid drugs only to "find themselves mired in a life of street drugs and crime."

While the issue of opioid use among athletes is addressed primarily in the research that focuses on the use of opioid drugs among young athletes, there is some research that points to their use among athletes in professional sports. Unfortunately, there is a general lack of statistical evidence published on the use of drugs by athletes, which may be attributed to the fact that athletes are typically less likely than non-athletes to report opioid abuse as well as the fact that opioids do not improve athletic performance and therefore cannot be explained away by anything more than a clear addiction.[3] What statistics do exist show that as much as 71% of former National Football League players interviewed by researcher reported that they were involved in the non-medical use of prescription opioid drugs during their careers, many of which were initiated into opioid drug use following sports-related injuries.[4] The research by Ford et al.[4] found that athletes, injured athletes, male athletes and injured male athletes were at greater risk for the use of opioid drugs. An especially compelling aspect of the use of opioids by athletes is that, unlike steroid or stimulant use, the use of opioids does not improve athletic performance and, in many cases undermines performance. Findings like these point to the fact that even athletes, who depend on the quality of their performance in their respective sporting events are vulnerable to the addictive attributes of opioid drugs like codeine, oxycontin, vicodin and even heroin.

The research demonstrates that the primary reason that athletes are vulnerable to opioid addiction is not because it improves their athletic performance. On the contrary, while opioid drugs can initially elicit the feelings of "euphoria and overall well-being," they work to reduce athletic performance because they cause the user to feel tired, sedated and confused as well as cause their respirations to decrease, none of which supports athletic performance.[5] Opioids can also have a devastating effect on athletic performance because they can change heart, lung and bone function.[5] The abuse of opioid drugs by athletes to achieve the perceivably positive symptoms of euphoria and sense of wellbeing can manifest in the use of IV drugs, oral drugs or both depending largely on how they were introduced to the drug, the type of drug that they have the greatest access to and issues like the ability to pay for such drugs. The research demonstrates that many athletes, including young athletes manage to extend their use of opioid drugs beyond their medical needs while some athletes start the use of opioid drugs in response to their use by peers who were initiated by a medical need. What is critical is that the friends and families of those athletes that find themselves addicted to opioids learn to identify the signs and symptoms of the addiction and support them in receiving the appropriate treatment for their addiction. Unfortunately, as much as the opioid epidemic throughout American society has reached epidemic proportions there is still an identifiable lack of information from sports-related substance abuse sources, including official sports organizations, on the signs of opioid abuse, with many focusing only on the symptoms of alcohol, stimulant and marijuana use and abuse.[6] Nevertheless, the general lack of statistics or other information on the use of opioids by athletes may be attributed to the fact that the proportion of opioid users in the United States who are athletes is relatively small however, the size of this population should not be the deciding factor on how much attention is paid and resources allocated to reducing and preventing their addiction.[2]

The opioid crisis has reached crisis proportions in America, touching every demographic and increasing in urgency as more Americans succumb to this addiction. The roots of this sinister epidemic started in the wide distribution of pain medications meant to help with acute and chronic pain. The result has been an opioid addiction that has resulted in people that would never otherwise consider using heroin to find themselves mired in a life of street drugs and crime. This is particularly true of athletes, who often suffer from chronic pain after pushing their bodies to the limit. When they are treated for pain with opioid medications, they may find themselves in a downward spiral that not only ruins their athletic prowess, but also leads to an addiction they cannot control. Doctors should refrain from widely prescribing pain medications for injuries that may not require the potency of opioids in an effort to avoid initiating and perpetuating cycles of addiction.

Athletes are accustomed to being in elite physical condition, and they may find that they are unable to pursue their goals if struggling with addition to opiates. Moreover, abuse and addiction can lead to other diseases and disorders (particularly if the drug is being injected intravenously) that would destroy any chance of continuing a career. The physical and physiological dependence on the opiates would become more important and all-consuming than their athletic careers.[7] The bigger issue, however, is when the prescribed medication ends, the addiction remains. The downward spiral includes the high cost of illegal opiates. When illegal opiates are no longer an option, people (including athletes) with addictions have no other choice than to turn to the cheaper heroin. This is just as effective, but far less expensive. The descent into heroin addiction forces athletes to become shadows of their former selves and to become involved in the world of illegal drugs. Athletes that move from prescription opiate addiction to heroin enter a world outside of illicit prescriptions and popping pills. The move to heroin is even more dangerous, as heroin addicts often ingest the drug intravenously (sometimes even sharing needles in the process) and the recent use of substances like fentanyl and carfantanyl have created a greater likelihood of overdose.

In addition to the physical and physiological implications of using narcotic medications recreationally and the dangers presented by their use, there is also a direct impact on the career of the athlete.[8] Athletes are often subject to frequent drug testing. It is a prerequisite to participating in their sport of choice. Athletes that develop an opiate addiction may find that they fail drug tests, mitigating them from participating in their sport of choice.[8] They may be eliminated, for life in some instances, for failing drug tests, particularly if they attempt to compete while under the influence. This is why athletes should not be provided with narcotics or any other medications/drugs that could be addictive or harmful to their health and impede their ability to compete.

The challenge of dealing with this issue is that athletes are sometimes subject to the advice of unscrupulous medical professionals that put competition over the health and wellbeing of the athletes. They often take pain medications without comprehending the risks for potential addiction or the impacts that these medications might have on their physical performance.

For these reasons, multi-disciplinary teams, such as rehabilitation counselors, social workers, and health educators, should be included in the decision-making along with coaches and physicians to determine the best paths for athletes. Understanding how people become addicted to drugs and the impacts that it has on their wellbeing and livelihoods is one area that in which knowledge and career planning for athletes can help them make informed decisions that may have life-long effects. There is already a burgeoning patient population in this area, perhaps, due to doctors making decisions in isolation. Interdisciplinary teams could help athletes make informed decisions that could possibly prevent significant increases if more athletes are given pain medication that could lead to addiction. This is especially true when athletes do not understand the consequences of taking these pain pills in the first place. Professional helpers, particularly addiction counselors, work with people struggling with addictions to reduce symptoms not increase them. However, some people such as athletes may need to feed the addictions rather than reduce the symptoms. As more athletes abuse prescription pain killers that they are prescribed, but do not necessarily need (specifically when there are non-opiate alternatives that are just as effective), the numbers of those addicted will continue to rise. There is life after sports but only if athletes are alive and well enough to experience it.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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Factors Influencing Speed of Collegiate Wheelchair Basketball Players

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ABSTRACT

Introduction

Sprinting determines a player's potential to initiate the next action. Previous studies have focused on wheelchair configuration and propulsion biomechanics for optimal performance in wheelchair sports.

Purpose

The purpose of this study was to determine influential factor(s) affecting the speed of collegiate wheelchair basketball players.

Methods

Eleven women (W: 22.3±4.8 yrs) and 13 men (M: 24.3±5.9 yrs) of University of Texas at Arlington's (UTA's) Wheelchair Basketball teams participated in this study. Participants were grouped based on gender and player classification (1.0-2.5 and 3.0-4.5). Dual-energy X-ray absorptiometry (DXA) scans assessed body fat percentage (BFP). Bilateral handgrip (kg) and 1-repetition maximum bench press tested muscle strength (lb). The first 15 ft of a 20 m sprint were video-recorded and analyzed to obtain values of trunk and elbow flexion (°) and contact and recovery time (sec).

Results

Lower classified (1.0-2.5) men and women had correlations between initial trunk and elbow flexion (M: r=0.73; W: r=0.84) and 15 ft time and initial elbow flexion (M: r=0.75; W: r=0.71). Low classified (1.0-2.5) men had negative correlations in the handgrips and both 15 ft and 20 m times (R hand 15 ft time: r=-0.89; R hand 20 m time: r=-0.75; L hand 15 ft time: r=-0.81; L hand 20 m time: r=-0.93). Body fat percentage influenced both 15 ft and 20 m times for high classified (3.0-4.5) men (15 ft: r=-0.74; 20 m=-0.78) and the 15 ft times for lower classified (1.0-2.5) women (r=0.88).

Conclusion

Initial elbow flexion and handgrip were important for lower classified (1.0-2.5) men. Low classified (1.0-2.5) women had faster 15 ft times with larger degrees of elbow flexion. Body fat percentage affected higher classified (3.0-4.5) male players. Additional factors may be identified in future research.

Keywords

Disabled sports; Biomechanics; Paralympic sport; Strength exercise.

INTRODUCTION

Research in the field of adaptive sport has been growing. Physical activity has tremendous benefits for an individual's health, physical functioning, and social relationships. Recently, competitive sport for people with disabilities has grown rapidly. Exercise develops social integration for people with disabilities by improving their self-confidence, self-competency and life quality.[1-3] In recent studies, the focus of adaptive sport has begun to focus on wheelchair propulsion biomechanics and optimal wheelchair configuration for the adaptive athlete to be most successful in his or her respective sport. The two major components of wheelchair sport performance are the athlete and the wheelchair.[3-5] Wheelchair sport biomechanics research focuses on the relationship between the user and the wheelchair, as well as their ability to generate force using their upper body. Wheelchair set up and configuration plays an important role in this relationship. Previous research has shown that there is a trade-off between wheelchair configuration and capacity to generate force.[6] The overall standards for the design of a wheelchair sports chair remains consistent for any wheelchair sport: the fit; minimizing weight while maintaining high stiffness; minimizing rolling resistance; and optimizing the sport-specific design of the chair.[7-9]

Wheelchair basketball is the most popular sport for athletes with disabilities.[10] According to the International Wheelchair Basketball Federation (IWBF), a player's level of trunk function directly affects the performance of different skills.[10] Individuals with a variety of disabilities can participate in wheelchair basketball. Spinal cord injury, cerebral palsy, musculoskeletal conditions, spina bifida, amputation and poliomyelitis are all lower-limb conditions that reduce an individual's ability to play running basketball similar to able-bodied players. Using sport-specific manual propulsion wheelchairs, performance depends on endurance, strength, speed, coordination and mobility.[11] In an attempt to provide parity and opportunity for individuals of all levels of function to play, players are grouped into categories or classes ranging from 1.0 (least physical function) to 4.5 (most physical function), and only a certain number of points are allowed on the floor at any given time. Classification is based on the function of the trunk, the upper extremities, the lower extremities and the hands, relying mostly on the movement and stability of the player's trunk.[1,5,9] Trunk movement and stability is based on the athlete's physical capacity to perform fundamental basketball movements such as pushing their chair, dribbling, shooting, passing, catching, rebounding, and reacting to contact.[9,12]

Similar to able-bodied athletes, wheelchair athletes look for more efficient ways to train and improve their technique or fitness.[5] For example, the ability to perform a sprint as fast as possible is important for wheelchair basketball players as speed determines the player's opportunity to take initiative of the next action.[13] Wheelchair basketball requires the players to perform numerous short periods of high or maximum intensity exercise and sprint actions.[10] More specifically, maneuverability and high accelerations from standstill or coasting is important for the player's ability to respond to and anticipate movements.[14] The most helpful studies have resulted from data gathered in circumstances that are close to the specific sport setting, with athletes in their own wheelchairs and in a field-based test.[13] Field-based tests create similar environments to the actions and movements of training and games.[12] Existing research studies concerning wheelchair basketball performance have included sprint tests, strength testing, analyses of hand rim wheelchair propulsion and body position in the chair, and comparison of player classifications.[1,4,9,10,13,14] The purposes of these studies have focused on wheelchair propulsion biomechanics, push characteristics in wheelchair court sprinting, and wheelchair configuration for optimal mobility performance in wheelchair sports.[1,6,10,11] This study focuses on the biomechanics of the wheelchair basketball player's manual propulsion and factors directly related to the participant rather than external factors or wheelchair configuration. Methods and procedures utilized in this study are similar to those of previous research in order to observe different features of the tests and the implications of any major findings. The purpose of this research study was to determine the most influential factor or factors that affect the speed of collegiate wheelchair basketball players by analyzing video-recorded 15 ft sprints and player information.

METHODS

Participants

All twenty-four (24) participants were current students between the ages of 18 and 45 years at the University of Texas at Arlington (UTA) on the roster for the men's or women's Movin' Mavs Wheelchair Basketball teams. All participants were not injured or recovering from an injury by the time of the first meeting with the primary investigator. Participants were excluded if they were pregnant, injured or recovering from an injury, if they were not students enrolled at the UTA, or if they were not wheelchair basketball players that compete at the collegiate level. Subjects were grouped based on gender and separated into two groups based on player classification (1.0-2.5 or 3.0-4.5). Correlations were calculated to determine any relationships between player information and video analysis variables with the times of the 15 ft and 20 m sprint times.[15] Subjects were grouped due to a smaller sample size, and previous research has used similar groupings to stratify players.[11,16] From a functional capacity stand point, the primary difference between a 2.5 and a 3.0 is control of trunk flexion and trunk extension. Class 3.0 players and above demonstrate complete control during trunk flexion/extension, whereas class 2.5 players and below demonstrate an inability to control the trunk during trunk flexion and are unable to return to an upright position via trunk extension.[5,9,17] In this study, participants were classified according to the Player Classification Manual of the IWBF: Class 1 (men: n=4; women: n=2), Class 1.5 (men: n=2; women: n=1), Class 2 (men: n=1; women: n=2), Class 2.5 (men: n=1; women: n=0), Class 3 (men: n=0; women: n=3), Class 3.5 (men: n=1; women: n=2), Class 4 (men: n=2; women: n=0), Class 4.5 (men: n=2; women: n=1). Disabilities in the lower classification (1.0-2.5) group included spinal cord injuries and spina bifida. Higher classification (3.0-4.5) disabilities included lower limb amputations and lower limb deficiencies.

Participants met with the primary investigator on three separate occasions. During the first meeting, the primary investigator reviewed the informed consent document with the subject, answered any questions or concerns from the subject, and the subject signed the form once comfortable with participating in the study. Participants were assigned a subject number upon signing the consent form. Participants also completed strength tests and provided basic player information during the first meeting. Basic player information consisted of age, mass, height, player classification, the size of the wheels on the subject's sports chair, and measuring the subject's wingspan. Age and height were self-reported. Mass was measured (Health O Meter Pro Plus weighing scale) with participants in their wheelchairs then the wheelchairs were weighed empty and that weight subtracted from the weight of the athlete plus the wheelchair. The size of the wheels on the sports chair were standard sizes and varied between 24 and 27 inches in diameter. Wingspan (m) was measured using a measuring tape.

Strength Testing

During the first meeting, participants completed a bilateral handgrip strength test similar to the procedure in the study conducted by Rodgers et al in order to provide an objective index of general upper body strength.[6] All participants used the same handgrip dynamometer (Jamar Technologies, Hydraulic Hand Dynamometer, Sammons Preston, Inc. Bolingbrook, IL, USA). Hand dominance was determined before starting any trials. All trials were completed with the participant seated in their day chairs, shoulder adducted and neutrally rotated, elbow by the side and flexed to a 90° angle, and forearm and wrist in neutral position. Participants alternated hands until completing three trials of each hand, resting 10-20 seconds between each trial to avoid the effects of muscle fatigue. During the rest period, the primary investigator recorded the results of the trial on the data collection sheet and reset the hand dynamometer back to zero.

Participants completed a one-repetition maximum (1 RM) bench press strength test similar to the procedure in the study conducted by Niewiadomski et al to measure the participant's ability to maximally lift weight through the full range of motion of a flat barbell bench press.[18] Depending on the participants' level of disability, the one-repetition maximum bench press was completed on a standard bench (3.0-4.5) or on the Olympic or the chest press BodyMax machine (1.0-2.5). All participants performed three total warm up sets. The first set consisted of five to ten submaximal repetitions with a weight equal to 40% of the participant's body weight. The following two warm up sets were between 50-60% of the participant's body weight and two to five repetitions. There were two minutes of rest between warm up sets. After warming up, the sets were single repetition as the weight approaches the participant's maximum. The 1-repetition maximum final weight lifted was achieved within four attempts. Exceeding four attempts risked compromising the participant's strength due to the volume of work already done. The weight for each set was recorded on the data collection sheet. The final 1 RM bench press value was used for data analysis.

Body Composition

The players on the men's and women's wheelchair basketball teams at UTA completed DXA scans. The scans provided the player's height (in) and mass (lb) and were validated by the player during the first meeting with the primary investigator. Body fat percentages from the scans were used for data analysis. DXA scans had to be completed before the player was allowed to begin any testing.

Speed Testing

Procedures for the second and third visit reflect those used by Yanci et al and consisted of the participant's completion of two separate video-recorded sprints.[10] Participants performed a maximum effort sprint for 20 m. The first 15 ft was video-recorded using a (GoPro Hero 6) camera set on "*Video*" at a resolution of 1080 at 60 fps and placed on a tripod in the middle of the 15-foot sprint near the edge of the key closest to the participant. The Motion Sensor and first PhotoGate pair, as well as the player in starting position, were kept in the frame. Participants started on the baseline of one side of the basketball court. Once the principal investigator (PI) had the recording system ready, participants were instructed to perform a maximum effort push, sprinting towards the baseline on the other end of the court. Participants began when they were ready from a stationary start. Sprint time began when the players passed through the first PhotoGate pair. The fastest video-recorded sprint time was used for data analysis.

The timing system used for data collection was a Brower Timing System with two PhotoGate pairs and TC-Motion Start using start on detection. Passing the PhotoGates initiated the start and finish of the 20 m sprint. One PhotoGate pair was placed at the 15-foot mark (4.57m) of the 20 m sprint to record the time for the 15-foot sprint. The other PhotoGate pair was placed at the 20 m mark for the end of the sprint. For the purposes of this study, the first PhotoGate pair was programed to the first beep (maximum of 10 m), and the other pair programmed to two beeps (maximum of 22 m). The TC-Motion Start sensor was placed at the starting baseline. The TC-Motion Start sensor beeped when the motion of the participant's movement was detected. The times for the 15-foot time, the split time, and the total 20 m sprint times were displayed on the screen of the TC-Timer. The TC-Timer was set to "*Chronograph Mode*" to show the display number, the 15-foot time, the split time, and the 20 m sprint time.

Kinovea Video Analysis

The participant's fastest video-recorded sprint time was used for video analysis. Data collected from the video recording included the total 20 m sprint time, 15-foot sprint time, number of pushes for the 15-foot sprint, number of pushes for the 20 m sprint, contact angle and recovery time of hands on the wheel, and trunk and elbow flexion. Video data was analyzed using Kinovea Motion Analysis software on a computer. Kinovea is a free software application used for 2D motion analysis and can measure passive and active range of motion, position, velocity, and acceleration. This data can be exported to a spreadsheet for further analysis. This software has been used in previous research examining the biomechanics of wheelchair sports and has been shown to be reliable compared to other 2D motion analysis software.[19-21]

A participant's fastest video recorded sprint was opened in the Kinovea software. Videos were played back at a speed of 15% to allow the primary investigator to observe hand contact and release on the wheel of the participant's sports chair. The contact and recovery times (sec) were measured using the time posted as "*position*" of the frame in the video. Contact times consisted of the entire duration at which the participant's hand contacted with the wheel of their sports chair. Recovery time was the amount of time the hand spent off the wheel before making contact again. Initial contact and recovery times (sec) were recorded and subsequent values for each were averaged.

Trunk and elbow flexion were also analyzed using Kinovea. Videos were played back at a speed of 15% to measure the degree of trunk and elbow flexions (°) at the same frame as the participant's first hand contact with the wheel of their sport's chair after recovery time. Using the angle tool, the primary investigator measured the degree of trunk flexion (°) by placing the vertex of the angle on the greater trochanter of the participant, one ray following the femur, and the second ray following the spine. Elbow flexion was measured by placing the vertex on the trochlea of the participant's elbow with one ray following the radius and ulna, and the second ray following the humerus. Internal angle measurements were used for both trunk and elbow flexion values.

Statistical Analysis

Data values from strength testing, DXA scans, and player information were recorded on an Excel spreadsheet. Correlations were calculated for men and women of both classification groups using Excel's "*CORREL*" function. Correlations with a strength of r=0.70 or higher were identified as influential to the speed of the wheelchair basketball players' sprints.[22]

RESULTS

Participant Data

Participants were grouped based by gender and separated into two groups based on player classification (1.0-2.5 or 3.0-4.5). According to Table 1, men (n=13) had a mean age of 21.63±2.83 years for the lower classification group (1.0-2.5) and 25.75±4.03 years for the higher classification group (3.0-4.5). Men in the 1.0-2.5 classification group had a mean mass of 74.49±25.07 kg and a mean height of 1.69±0.33 m. High classified (3.0-4.5) men had a mean mass of 82.82±6.62 kg and a mean height of 1.76±0.11 m. Wingspans were calculated as 1.74±0.24 m for the lower class (1.0-2.5) and 1.81±0.09 m for the higher class (3.0-4.5). Mean body fat percentages for the men were 26.65±12.48 percent for the 1.0-2.5 class and 26.99±5.01 percent for the 3.0-4.5 class.

Women (n=11) had a mean age of 23.00±7.35 years for the 1.0-2.5 classification group and 21.67±1.37 years for the 3.0-4.5 classification group. The low classification (1.0-2.5) group had a mean weight of 54.85±3.87 kg and a mean height of 1.56±0.09 m. High classified (3.0-4.5) women had a mean weight of 69.91±14.60 kg and a mean height of 1.68±0.15 m. Wingspans were calculated as 1.62±0.09 m for the lower class (1.0-2.5) and 11.69±0.12 m for the higher class (3.0-4.5). Mean body fat percentages for the women were 42.13±6.65 percent for the 1.0-2.5 class and 37.31±7.25 percent for the 3.0-4.5 class.

Table 1. *Participant Data*

Gender	Classification Group	Age (yr)	Weight (kg)	Height (m)	Wingspan (m)	Body Fat (%)
Men (n=13)	1.0-2.5 (n=8)	21.63±2.83	74.49±25.07	1.69±0.33	1.74±0.24	26.65±12.48
	3.0-4.5 (n=5)	25.75±4.03	82.83±6.62	1.76±0.11	1.81±0.09	26.99±5.01
Women (n=11)	1.0-2.5 (n=5)	23.00±7.35	54.85±3.87	1.56±0.09	1.62±0.09	42.13±6.65
	3.0-4.5 (n=6)	21.67±1.37	69.91±14.60	1.68±0.15	1.69±0.12	37.31±7.25

Strength Testing

According to Table 2, the men in the lower class (1.0-2.5) group had a mean handgrip strength of 42.05±5.42 kg for the right hand and 42.67±7.22 kg for the left. The 1-repetition maximum bench press mean was 203.75±54.43 pounds. The higher class (3.0-4.5) group had a mean handgrip strength of 41.93±7.07 kg for the right hand and 45.13±15.55 kg for the left. The 1-repetition maximum bench press mean was calculated at 228.75±46.08 pounds.

The lower class (1.0-2.5) women had a mean handgrip strength of 25.00±5.83 kg for the right hand and 23.60±6.65 kg for the left hand. For this group, the 1-repetition maximum bench press mean was 103.00±9.75 pounds. Women in the higher classification (3.0-4.5) group had a mean handgrip strength of 25.72±5.62 for the right hand and 28.00±5.64 for the left. The 1-repetition maximum bench press for this group was 135.20±19.69 pounds.

Table 2. *Strength Testing Data*

Gender	Classification Group	Handgrip Strength Right (kg)	Handgrip Strength Left (kg)	1RM Bench Press (lb)
Men (n=13)	1.0-2.5(n=8)	42.05±5.42	42.67±7.22	203.75±54.43
	3.0-4.5(n=5)	41.93±7.07	45.13±15.55	228.75±46.08
Women (n=11)	1.0-2.5(n=5)	25.00±5.83	23.60±6.65	103.00±9.75
	3.0-4.5(n=6)	25.72±5.62	28.00±5.64	135.20±19.69

Kinovea Video Analysis

According to the video analysis Table 3a, the mean 15 ft for lower class (1.0-2.5) men was 2.25±0.15 seconds. The 20 m time was 5.74±0.30 seconds. The mean number of pushes for the 15 ft distance was 5.71±0.76 pushes and the 20 m distance had a mean of

13.29±2.21 pushes. The higher class (3.0-4.5) group had a 15 ft mean time of 2.07±0.09 seconds, a 20 m mean time of 5.89±0.28 seconds, a mean number of pushes of 5.00±0.63 pushes for the 15 ft distance, and 13.17±1.94 pushes for the 20 m distance.

Table 3a displays the means for the women in the low class (1.0-2.5) 15 ft time as 2.36±0.11 seconds and 5.89±0.28 seconds for the 15 ft distance. The mean number of pushes for the 15 ft distance was 6.00±0.00 pushes and 13.17±1.94 for the 20 m distance.

Table 3b shows the means for the degrees of trunk and elbow flexions. For low class (1.0-2.5) men, a mean angle of 49±14 degrees was calculated for the initial trunk flexion and a mean angle of 56±12 degrees was determined for the trunk flexion. Initial elbow flexion had a mean of 98±8 degrees while the elbow flexion was 102±8 degrees. The higher class (3.0-4.5) men had a mean of 54±7 degrees of trunk flexion and 60±16 degrees of initial trunk flexion. The initial elbow flexion mean for this group was 101±10 degrees and 105±13 degrees for elbow flexion.

The women in the lower classification (1.0-2.5) group had a mean initial trunk flexion of 45±7 degrees and a mean of 60±7 for trunk flexion. The mean for initial elbow flexion was 99±8 degrees and 111±6 degrees for the elbow flexion. Women in the higher class (3.0-4.5) had a mean initial trunk flexion of 49±7 degrees and a mean of 53±4 degrees for trunk flexion. For this group, the mean was 99±8 degrees for initial elbow flexion and 105±13 degree for elbow flexion.

The contact and recovery times (sec) were recorded in Table 3c. For the men's lower classification (1.0-2.5) group, mean initial contact time was 0.44±0.11 seconds and 0.20±0.04 seconds for contact time. Initial recovery time and recovery time had means of 0.21±0.06 and 0.23±0.06, respectively. The high class (3.0-4.5) group had a mean initial contact time of 0.45±0.17 seconds and a mean contact time of 0.22±0.04 seconds. The mean for initial recovery time was 0.19±0.01 seconds, with a mean recovery time of 0.21±0.02 seconds.

The women's lower classification (1.0-2.5) group had a mean initial contact time of 0.46±0.08 seconds and a mean contact time of 0.26±0.01 seconds. Initial recovery time and recovery time means for this group was 0.19±0.04 and 0.25±0.03, respectively. The 3.0-4.5 classification group for the women had a mean initial contact time of 0.51±0.12 seconds. The contact time was recorded as 0.22±0.02 seconds. The mean for initial recovery time was calculated at 0.25±0.05 seconds and 0.26±0.03 seconds for recovery time.

Table 3a. *Kinovea Analysis of Sprint Times (Sec) and Number of Pushes*

Gender	Classification Group	15 ft Time (sec)	20 m Time (sec)	15 ft Pushes	20 m Pushes
Men (n=13)	1.0-2.5(n=8)	2.25±0.15	5.74±0.30	5.71±0.76	13.29±2.21
	3.0-4.5(n=5)	2.07±0.09	5.36±0.23	5.50±0.58	12.50±1.29

Table 3b. *Kinovea Analysis of Trunk and Elbow Flexions (°)*

Gender	Classification Group	Initial Trunk Flexion (°)	Trunk Flexion avg (°)	Initial Elbow Flexion (°)	Elbow Flexion avg (°)
Men (n=13)	1.0-2.5(n=8)	49±14	56±12	98±8	102±8
	3.0-4.5(n=5)	60±16	54±7	111±12	113±6
Women (n=11)	1.0-2.5(n=5)	45±7	60±7	99±8	111±6
	3.0-4.5(n=6)	49±7	53±4	101±10	105±13

Table 3c. *Kinovea Analysis of Contact and Recovery Times (Sec)*

Gender	Classification Group	Initial Contact Time (sec)	Contact Time (sec)	Initial Recovery Time (sec)	Recovery Time (sec)
Men (n=13)	1.0-2.5(n=8)	0.44±0.11	0.20±0.04	0.21±0.06	0.23±0.06
	3.0-4.5(n=5)	0.45±0.17	0.22±0.04	0.19±0.01	0.21±0.02
Women (n=11)	1.0-2.5(n=5)	0.46±0.08	0.26±0.01	0.19±0.04	0.25±0.03
	3.0-4.5(n=6)	0.51±0.12	0.22±0.02	0.25±0.05	0.26±0.03

Correlations

According to the correlations (Table 4) calculated from participants' strength testing, and video analysis data, the strongest relationships for the male players in the lower classification group (1.0-2.5) were between handgrip strength and the 15 ft time (R: r=-0.89; L: r=-0.81). Handgrip strength had a strong influence on 20 m sprint times as well (R: r=-0.75; L: r=-0.93). An additional correlation was found between the 15 ft time and the initial elbow flexion (r=0.75). Body fat percentage (r=0.88), 1-repetition maximum bench press (r=-0.75)), trunk flexion (r=0.70), elbow flexion (r=-0.83), and initial elbow flexion (r=0.71) resulted in faster 15 ft sprint times for women in the lower classification group (1.0-2.5). Faster 20 m times for this group were observed with lower body weight (kg) (r=1.00) and initial trunk flexion (r=0.82). For the higher classification groups, men with faster 15 ft times had lower body fat percentages (r=-0.74), and trunk flexion (r=0.78), initial elbow flexion (r=0.85). The 20 m time was affected by the players' left handgrips (r=0.72), body fat percentage (r=-0.78), and initial elbow flexion (r=0.81). Strong correlations were not determined for women in the high classification (3.0-4.5) group. However, moderate correlations were observed between trunk flexion and 15 ft time (r=0.62), and initial trunk and elbow flexions and 20 m times (trunk: r=0.63; elbow: r=0.65).

Table 4. *Correlations*

Gender	Classification	Variables	Correlation
Men (n=13)	1.0-2.5(n=8)	20 m time (sec) and handgrip (L)	r=-0.93
		15 ft time (sec) and handgrip (R)	r=-0.89
		15 ft time (sec) and handgrip (L)	r=-0.81
		20 m time (sec) and handgrip (R)	r=-0.75
		15 ft time (sec) and initial elbow flexion (°)	r=0.75
	3.0-4.5(n=5)	15 ft time (sec) and initial elbow flexion (°)	r=0.85
		20 m time (sec) and initial elbow flexion (°)	r=0.81
		15 ft time (sec) and trunk flexion (°)	r=0.78
		20 m time (sec) and body fat (%)	r=-0.78
		15 ft time (sec) and body fat (%)	r=-0.74
		20 m time (sec) and handgrip (L)	r=0.72
Women (n=11)	1.0-2.5(n=5)	20 m time (sec) and weight (kg)	r=1.00
		15 ft time (sec) and body fat (%)	r=0.88
		15 ft time (sec) and elbow flexion (°)	r=0.83
		20 m time (sec) and initial trunk flexion (°)	r=0.82
		15 ft time (sec) and 1RM bench press (lb)	r=0.75
		15 ft time (sec) and initial elbow flexion (°)	r=0.71
		15 ft time (sec) and trunk flexion (°)	r=0.70
	3.0-4.5(n=6)	20 m time (sec) and initial elbow flexion (°)	r=0.65
		20 m time (sec) and initial trunk flexion (°)	r=0.63
		15 ft time (sec) and trunk flexion (°)	r=0.62

DISCUSSION

This study aimed to identify specific factors that strongly contributed to a collegiate wheelchair basketball's speed in order to provide wheelchair basketball coaches and players specific player data as well as fitness aspects players need to focus on to improve their quality of play. This study focused on the first 15 ft or 4.57 m of a maximum effort 20 m sprint to observe the player's movements during the initiation of their sprint. This movement is observed most often during play with changes, in direction, chasing an opponent, or breaking away from a defender. These scenarios depend on a player's ability to quickly accelerate. Identifying influential factors for this initial action could provide applicable information to coaches and players to improve their sprinting technique.

Overall, stronger correlations were established for the lower classification groups (1.0-2.5) for both men and women. Handgrip strength and elbow flexion were especially important for the male players' sprint times while elbow flexion and body fat percentage affected the sprint times for the female players. The higher classification group (3.0-4.5) males were more influenced by body fat percentage, trunk flexion, and initial elbow flexion. The moderate correlations for the women in the higher classification group correspond with the findings of the other groups with trunk and elbow flexions having the strongest effects on the sprint times. Lower classified players were able to push their wheels with more force, especially for the 15 ft time, due to the increased grip strength. The handgrip test measured the forceful flexion of all finger joints with the maximum voluntary force exerted by the subject. This force is placed on the wheel at the beginning of a push. The stronger the force, the harder the wheel is pushed, propelling the player to move faster across the floor.

In addition to handgrip strength, elbow flexion and body fat percentage had a strong influence on the lower classification sprint times. Higher classification males were also affected by body fat percentage. A player with a lower body fat percentage could get his or her trunk more parallel to the floor, achieving greater trunk flexion. Greater trunk flexion inherently activates triceps extension increasing the force on the wheel as the player pushes. Both higher classification males and females had faster sprint times depending on their trunk and elbow flexion. By definition of the Functional Classification system, players with higher classifications are more stable[5,9,17] and are able to utilize a seating position that allows for more range of motion of the trunk. This is consistent with previous work by Yanci et al who demonstrated that seating position can play a significant role in the ability to generate power during the initial push of wheelchair propulsion.[10] Players with lower classifications (in other words, less functional capacity) tend to sit in a position that puts their knees higher than their hips. This provides more stability, but adversely affects trunk range of motion, and therefore limits the ability of the athlete to use their trunk in the generation of power. Overall, elbow flexions strongly influenced the players' sprint times. The degree of elbow flexion depended on the contact angle on the player's wheel. The larger degree of elbow flexion allowed the player to reach further back on their wheel. A grip farther back on the wheel resulted in greater contact time on the wheel during the player's push, covering more distance faster with a single push. This ultimately results in a faster sprint time. Triceps strength has long been known to contribute to force application during wheelchair propulsion,[6] and the findings that greater elbow flexion that allows for greater contact time on the wheel resulted in faster sprint times supports this notion.

LIMITATIONS

Potential limitations in this study could result from the grouping of the participants. Due to the small number of participants, subjects were placed into only two classification groups: low (1.0-2.5) and high (3.0-4.5). Different correlations may be determined if subjects were placed in more explicit groups to obtain more accurate and specific group data. This will allow for further comparison of data to determine trends in correlations between groups. It would be helpful if there were more subjects for each gender to be able to separate participants into more distinct groups. Additionally, one of the subjects in the lower classification group was classified lower due to limb length discrepancies rather than deficiencies in trunk function. The nature of the functional classification system allows for the deduction of classification points if the player is disadvantaged due to a number of reasons (limb length discrepancies, range of motion deficiencies, etc.), therefore this system in isolation is not always an indicator of trunk function. Due to the small subject size this may have skewed the results of the lower classification group with regard to several variables.

Additionally, this study did not differentiate between active and passive trunk flexion. Players with lower functional classifications often do not have the ability to actively bring their trunk back up to a seated position without using their hands,[17] suggesting that any initial trunk flexion is passive in these players. Future studies should examine the role of active vs passive trunk flexion in wheelchair propulsion.

Further research should be completed to determine stronger correlations for female collegiate wheelchair basketball players with higher classifications (3.0-4.5). While strong correlations were not found for this group in this study, moderate correlations of the trunk flexion for the 15 ft time (r=0.62), and the initial trunk and elbow flexions on the both the 15 ft and 20 m times were identified during this study. Based on the correlations associated with trunk flexion, it may be helpful to investigate the effects of back and abdominal strength on a wheelchair basketball player's speed using an abdominal or back strength test.

Future studies may find additional results if the entire 20 m push, rather than the first 15 ft (4.57 m), is video-recorded. Video analysis of the entire 20 m distance can provide additional correlations or data trends for a maximal effort push. An improvement in sprint times may be observed if subjects are asked to complete a few practice sprints to warm up before the recorded sprint. The practice sprints will allow the participants to get a feel for how long the distance is and how hard to push to perform the fastest sprint possible with maximum effort.

PRACTICAL IMPLICATIONS

Workout and training programs should encourage shoulder flexibility and increasing the range of motion in the shoulder joint to allow the player to reach further back on the wheel of their sports chair. Additionally, coaches should encourage players to get their torsos as parallel to the floor as possible when sprinting to assist in creating a greater degree of elbow flexion.

CONCLUSION

This study has identified certain variables that can affect a wheelchair basketball player's speed. Initial elbow flexion was a moderate to strong correlation for both men and women as well as both the low and high classification groups. The results of this study can be shared with collegiate wheelchair basketball coaches and players to provide guidance in how to improve a player's ability for optimal sprinting.

CONFLICT OF INTEREST

None of the authors have any conflict of interest.

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SPORTS AND EXERCISE MEDICINE

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Short Communication

Diagnosis of Overtraining and Overreaching Syndrome in Athletes

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Overtraining (OT) is one of the most popular topics between coaches and researchers. The problem of this syndrome has been well-known for 70-years, however, the mechanism that induces OT remains unclear.[1-3] Many recent papers have referred to the work of Kreider et al[4] for the definitions of overreaching (OR) and OT.[1-3]

Overreaching: An accumulation of training and/or non-training stress resulting in short-term decrement in performance capacity with or without related physiological and psychological signs and symptoms of maladaptation in which restoration of performance capacity may take from several days to several weeks.

Overtraining: An accumulation of training and/or non-training stress resulting in long-term decrement in performance capacity with or without related physiological and psychological signs and symptoms of maladaptation in which restoration of performance capacity may take several weeks or months.

These definitions suggest that the difference between OT and OR is the time that is needed from the recovery. For example, the recovery from OT syndrome (OTS) may require weeks to months while for OR resolved within days to weeks. Several psychological disturbances such as psychosocial stressors, sleep disorders and illness, decreased vigor, increased fatigue and reduced performance and the athletes will need weeks or months to recover.[5]

Many researchers have tried to examine the effects of overtraining in athletes.[6] Although, as there is no diagnostic tool to identify an athlete with OT or OR syndrome, diagnosis can only be made by excluding all other possible influences on changes in performance and mood state.[1] So, that prevention is still the best cure, and to avoid the onset of OR or OT athletes should record daily their training load, using a daily training diary or training log.[3] Athletes, coaches and researchers need to recognize the early warning signs OR or OT. However, there are recognized physiological and biochemical parameters which are associated with overtraining, for example a low iron or testosterone-level.[7]

The OT or OR syndrome represents one of the most feared complications in competitive athletes and concern coaches and researchers,[8] because the recovery of athletes may require weeks to months. The aim of strength and conditioning is to improve performance of athletes. Nonetheless, there is a thin line between maximal performance and OT or OR. As a consequence, when an intensive, excessive and extended training are applied concurrent with inadequate recovery, many of the positive physiological alterations associated with physical training are reversed with OT or OR.[2] Overreaching is often used by athletes during a typical training cycle to improve performance. If the intensity, the load and the duration of the training are not reduced, OR leads to OT.[1] However, athletes who are diagnosed with OTS may take months or years to completely recover, this means that an athlete's career may be seriously compromised and there are many cases that athletes stopped the athletic career due to OT or OR.[1]

OT or OR is recurrent problem and is often observed in high performance athletes and in different sports. More especially, studies have reported that the symptoms of OTS appeared in >60% of distance runners during their athletic careers, >50% of professional soccer players during a 5-month competitive season, and 33% of basketball players during a 6-week training camp.[2]

DIAGNOSIS

Diagnosis of OTS and OR is not simple. Unfortunately, diagnosis of OTS cannot be made definitively with one biomarker, there are a few markers that may be considered in the elite athlete.[3,8,9] From the literature the most used biomarkers are urea (5-7 mmol/L), uric acid (237-449 μmol/L), ammonia (70-80 μmol/L), and creatine kinase (100-250 U/L).[8] However, there are many others biomarkers that should be examined. However, one may be able to estimate training load and the body's response with the following: salivary immunoglobulin A, serum testosterone: cortisol and overnight urinary cortisol: cortisol ratio.

The study of Barron and Noakes,[10] was one of the first studies that investigate the possible mechanisms of overtraining. Four overtrained athletes were investigated in total, with only two subjects given actrapid insulin alone. The prolactin responses of the subjects to this challenge ranged from <1 to 98 ng/min/mL. Additionally, subjects were reported to be recovered after a 4-week rest period. This suggests that the athletes were, indeed overtrained; however, performance was not measured in this study. In the study of Rowbottom et al.[11] examined a combination of parameters in ten athletes who were diagnosed as overtrained. Athletes reported difficulty maintaining their training program and fatigue. Resting hematological, biochemical, and immunological measures were made and compared with established normal ranges. The only measured parameter that was significantly different to normal ranges was glutamine, indicating that in most haematological, biochemical and immunological aspects, these athletes were not different from normal controls.

In the study of Hedelin et al.[12] examined overtrained athletes and found a decrease resting heart rate (-4.8%). The athletes reported accumulated fatigue and reduced performance, however, the change in performance was not reported and the type of exercise test was unclear. Compared with normally subjects, the overtrained subjects had an increase in high-frequency and total power in the lying position during intensified training, which decreased after recovery.

Koutedakis and Sharp[13] examined 257 elite athletes who were members of British National Teams in a variety of sports over a 12-month training season. They found that 15% of athletes were classified as overtrained and in 50% of these cases a state of overtraining was said to have developed in the 3-month competition phase.

Meeusen et al[5] published a test protocol with two consecutive maximal exercise tests separated by four hours. With this protocol they found that in order to detect signs of OTS and distinguish from normal training responses or functional OR, this method may be a good indicator not only ofthe recovery capacity of the athlete but also of the ability to normally perform the second bout of exercise. The use of two bouts of incremental exercise to volitional exhaustion to study neuroendocrine variations identified an exercise-induced increase of adrenocorticotrophic hormone, prolactin, and growth hormone.[8] The test could be therefore used as an indirect measure of hypothalamic-pituitary capacity. In a functional-OR stage a less pronounced neuroendocrine response to a second bout of exercise on the same day is found,[14,15] while in a non-functional OR stage the hormonal response to a two-bout exercise protocols hows an extreme increased release after the second exercise trigger.[10] With the same protocol it has been shown that athletes suffering from OTS have an extremely large increase in hormonal release in the first exercise bout, followed by a complete suppression in the second exercise bout.[5] This could indicate a hypersensitivity of the pituitary followed by an insensitivity or exhaustion afterwards. Previous reports that used a single exercise protocol found similar effects.[5] It appears that the use of two exercise bouts is more useful in detecting OR for preventing OT. Early detection of OR may be very important in the prevention of OT.

On the other hand, there are many studies that report diagnosis of OR. Numerous studies have reported changes in a variety of physiological and biochemical responses to intensified training. In a study of Hooper et al reported a 2.4% increase in performance times in swimmers who were overreached compared with 1.1% decrease in well trained swimmers. Both Jeukendrup et al[16] and Snyder et al[17] reported a decrease in maximal aerobic power achieved during a graded incremental cycle test to exhaustion of approximately 3-4% as a result of 2-weeks of intensified cycling training. Jeukendrup et al[16] reported a slightly larger decline in performance (5%) when the same subjects completed a time-trial test with an approximate duration of 15-minutes. When researchers incorporate time to fatigue assessments, a larger decline in endurance capacity is evident. Fry et al[18] and Urhausenet al[19] reported a 29% and 27% decline in performance, respectively, when using a time to fatigue protocol.

PREVENTION

Diagnosis of OT or OR is difficult, authors agree that is important to prevent them.[6] Moreover, one proposed method it is of utmost importance that athletes record daily their training load, using a daily training diary or training log.[9,20]

In the studies of Meeusen et al[3] reported four methods most frequently used to monitor training and prevent OT or OR are as follows: retrospective questionnaires, training diaries, physiological screening, and the direct observational method. Also, the psychological screening of athletes and the Borg Rating of Perceived Exertion (RPE) have received more and more attention now-a-days.

In the reviews of Kreherand Schwartz[9] and Kreher[20] reported that major components of prevention are screening and education. One should educate athletes at risk for overtraining that one ofthe initial signs of overreaching is increased rating of perceived exertion for a given workload. In addition, sports medicine providers may consider preemptively asking if training has increased to compensate for decreases in performance. History of athletes should include inquiry about training (monotony, excessive load, sudden increase, caloric/hydration needs in relation to load) and personal stressors (interpersonal, family, sleep, travel).

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SPORTS AND EXERCISE MEDICINE

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Original Research

Effectiveness of Compression Garments on Selected Physiological, Perceptual and Performance Measures While Traversing Austere Conditions at Altitude: A Pilot Study

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ABSTRACT

Background
Compression garments (CGs) have increased in popularity within recreational and competitive athlete populations.

Purpose
The purpose of this study was to examine the effect of CGs on physiological, performance, and perceptual measures while running on uneven terrain at higher altitude.

Methods
Nine recreationally active males participated in two trail running sessions (7 km: uphill section 3.5 km, and downhill section 3.5 km). In the first session, participants completed the 7 km trail while wearing regular athletic clothing. Seven days later, participants then completed the same 7 km trail wearing CGs. Physiological and performance measures were collected at the baseline, during the trail run, immediate post-run, and 24, 48, 72 hours after the trail run.

Results
Results showed no significant differences in time to completion (p=≥0.05). However, there were significant differences in physiological load (p=0.04), training load (p=0.01), average physiological intensity (p=0.05), and estimated caloric expenditure (p=0.02) between trials. Significant improvement in vertical jump height and peak anaerobic power in watts (p=0.04), isometric strength (p=0.03), and post-exercise pain ratings at 48 (p=0.01) and 72 (p=0.038) hours post exercise were found under the CG condition.

Conclusion
Although there were no differences in time to complete the runs in both conditions (with and without CGs), the significant differences in the physiological measures suggests that the CGs may have an ergogenic effect when participating in trail running activities at a higher altitude. Therefore, wearing CGs may increase exercise efficiency and capacity, leading to a possible increase in recovery from training and activity.

Keywords
Vertical Jump; Isometric Strength; Performance; Endurance; Running.

Abbreviation
PAPw-Peak anaerobic power in watts

INTRODUCTION

Compression garments (CGs) have traditionally and extensively been used in therapeutic medicine.[1,2] These garments have primarily been used with vascular patients as a means to reduce edema by improving venous return and peripheral circulation,[1,3] which may also provide an ergogenic benefit within athletic populations.[4,5] The compression provided by CGs used in athletes generally ranges from 6 to 45 mmHg of pressure, and range from lower leg stockings to full body compression clothing. Higgins et al,[6] found that competitive netballers wearing CGs were able to cover greater distances at faster speeds when compared to wearing their traditional netball garments (>20%), as well as when wearing placebo CGs (≥34%). The researchers speculated that the use of CGs may improve circulatory function during low-to-moderate intensity activity as well as reduce energy expenditure.[6] Scanlan et al.[7] examined the physiological effects of compression tights during endurance cycling. Interestingly, the results reported no improvement in time trial performance, but there was an increase in physiological efficiency.[7]

Research by Doan et al[8] investigated the impact of compression shorts on 60 m sprint speed,and vertical jump performance amongst 10 male (age 20±0.9) Division 1 track athletes. Participants in the study experienced significant reductions in muscle oscillations (anterior to posterior) upon landing from a vertical jump and had a significantly greater jump height while wearing CGs; however, there were no significant differences in 60 m sprinting speed.[8] Doan and colleagues suggested that the CGs may have acted as an ergogenic aid by providing greater joint support.[8] This may, in part, explain the greater squat depth (1.8 cm) (p=0.024) achieved when compared to the control condition.[8] Vercruyssen et al[9] examined the effects of CGs on physiological and performance measures in highly trained trail runners following a short trail run. Results from their study suggests that CGs did not provide any significant performance enhancements in running economy.[9] However, Bieuzen et al[10] discovered that perceived muscle soreness was significantly lower among participants after wearing CGs, when compared to the control condition, following a fatiguing bout of off-road running in well-trained runners. These researchers also stated that another possible beneficial effect of wearing CG's was improved muscle function (i.e, isometric peak force and countermovement jump performance) 1-hour and 24-hours post-run. These findings may have significant implications for individuals that are required to traverse various trails and uneven terrain, and are then required to perform tasks that require strength and power.

Research investigating the use of CGs for performance enhancement has been conducted in both laboratory[11,12] and field[13] setting with trained trail runners.[9,10,14] In practice, CGs are often worn by recreational (novice) populations because of the garment's aesthetic value, rather than its functionality[16] and with the assumption that it decreases soreness and increases performance. However, these may be based on the marketing messages by companies claiming that their products will improve athletic performance and increase physiological efficiency to increase exercise capacity.[17] While many studies have examined the effects of CGs on exercise performance, none have investigated these effects among recreationally trained individuals in austere conditions at relatively higher altitudes.[13,14,17] Therefore, the purpose of this study was to examine the effect of CGs on physiological, performance, and perceptual measures while traversing uneven terrain at a relatively higher altitude.

METHODS

Participants

Thirteen participants were initially recruited, of which, three withdrew before data collection, and one participant was excluded because environmental conditions were not consistent between his data collection session and those of the remaining group. Nine (n=9) recreationally active males (age: 26.9±4.9 years; hight: 178.22±5.89 cm; weight: 85±13.3 kg),that participated in vigorous intensity activities at least twice per week for a minimum of one year, and currently experienced no skeletal or neurological injuries, participated in the study. None of the participants had previous experience in trail running competitions. Ethics approval was obtained from the University of Colorado, Colorado Springs Institutional Review Board (#14-219, Date: 07/28/14). Subjects were recruited *via* flyers and word of mouth advertising from the university, city, and surrounding communities. Prior to testing, informed consent was obtained from each participant following which they completed a medical history and physical activity readiness questionnaire.

Procedures

Participants served as their own control in a repeated-measures experimental design completing two testing trials, one in self-selected normal active wear (control), and the other wearing graduated lower-body compression garments (CGs) (treatment). Testing trials were limited to two, in order to accurately investigate the effects CGs had on the physiological, performance, and perceptual measures.[18] CGs were ankle long compression tights made of a circular knit 50 Denier Lycra fabric (2XU, Melbourne, Australia) and participants were provided the correct size and fit for the individual (according to the manufacturer's recommendations). The control garment consisted of loose-fitting conventional shorts or sweat pants selected by the participants. Both the CG's and control garments in this study were new and had never been worn prior to testing.

Participants were instructed to complete a dietary intake record for the 24 hours prior to the first trial; avoid consuming any food, alcohol or caffeine three hours prior to testing; and encouraged to consume at least 500 mL of water two hours prior to testing.[19] Participants were instructed to match these consumption patterns as closely as possible for the 24 hours prior to the second trial.

For the first testing session, subjects met at a mutually agreed upon time with the investigators at the Barr Trail trailhead in Manitou Springs, Colorado, US. The section of the Barr Trail used for testing gains over 600 m of elevation with a beginning elevation of 1990 m and a peak height of 2606 m. The out and back route was 7 kilometers (3.5 km ascent; 3.5km descent) (Figures 1 and 2). The route completed by the participants was primarily covered by loose dirt, rocks and roots. One of the investigators was positioned at the turn-around point, so the participants knew to turn around and begin the descent portion of the trial.

Figure 1. *Graphical View of the Trail*

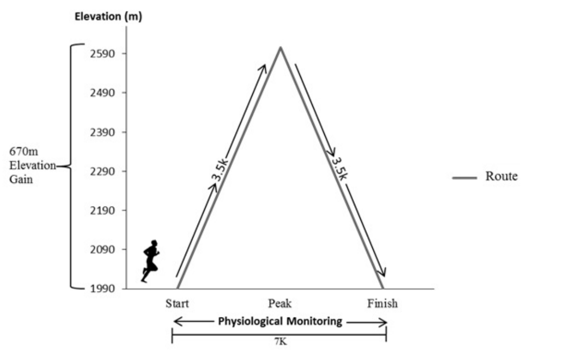
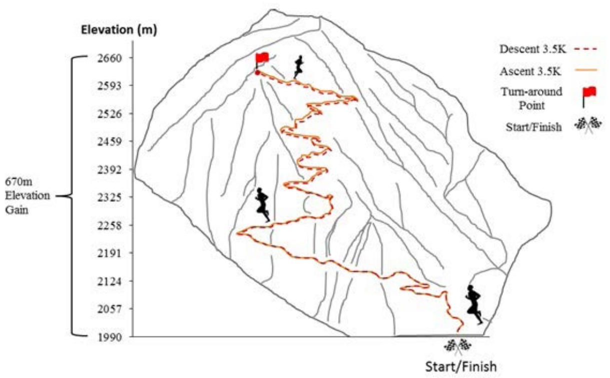


Figure 2. *Outline View of the Trail*



Prior to the start of each trial, ambient temperature and relative humidity were recorded using a digital psychrometer to ensure consistent environmental conditions during both trials.

Participant anthropometric data were then collected using a Tanita Body Composition Analyzer (TBF-310, Tanita Corporation, Inc., Tokyo, Japan) and a standard tape measure. Blood lactate (BLa) was analyzed by collecting a fingertip capillary blood sample and a portable lactate analyzer (Lactate Plus, Sports Resource Group, Inc.). Blood glucose was also measured at this time using a fingertip capillary blood sample and analyzed with a portable glucometer (Reli On, Ultima Blood Glucose Monitor, Arkray-Inc., Kyoto, Japan).

Participants were then instructed to perform a self-selected warm-up for approximately five minutes prior to power and strength testing. Participants were provided a 5-minute familiarization session where an investigator explained and demonstrated each of the performance measures to the participants prior to actual testing. Following the explanation and demonstration, the participants were allowed three attempts at each performance measure.

Once the warm-up and familiarization session was complete, participants performed five successive countermovement jumps (CMJ), with 10 seconds rest allowed between efforts, on aswitch matt (Just Jump, Probiotics Inc., Huntsville, Alabama, US). The CMJ was performed by swinging the arms back, while flexing the knees and hips, drop to a self-selected depth, and then explode off the ground as high as possible while swinging the arms forward and up to achieve maximum height. This device utilizes a switch matt to estimate vertical flight time by measuring displacement time and utilizing an equation based on a constant gravitational force. Peak anaerobic power in watts (PAPw) was then calculated for each jump using the Sayers peak power equation.[5]

Upon completion of these jumps, participants were allowed 2 minutes rest, and then were asked to perform three successive isometric mid-thigh pulls using a back/leg dynamometer (Medico Inc., Phoenix, Arizona, US). A chain, which connects the scale on one end and a handle on the other, was adjusted so that the knees were bent at approximately 110 degrees. Participants were instructed to grab the handle of the dynomometer with the grip they use for the dead lift exercise. While maintaining good spinal posture, straight arms and feet flat on the base of the dynamometer, the participants explosively pulled the handle upward as hard and as fast as possible. Participants were allowed three trials to generate as much force as possible. Paricipants were given 1 minute of rest between attempts on this assessment, and each measurement was recorded to the nearest kilogram.

Participants were then fitted with a Zephyr Bioharness 3™ chest strap (Zephyr Technology Corporation; Annapolis, Maryland, US). This device was used to capture physiological data including heart rate, heart rate variability, estimated core temperature, respiration rate, posture, speed, distance and peak acceleration, physiological and mechanical load, physiological and mechanical intensity, training load, activity level, and estimated caloric expenditure. Once the Zephyr Bioharness 3™ chest strap was inplace, participants were allowed to begin their ascent up the Barr Trail. Participants were instructed to complete the trail run as fast as they could.

Immediately upon completion of the route, another fingertip capillary blood sample was collected and the same procedures for the pre-testing session were repeated. Participants were also contacted *via* phone or text message at 24, 48 and 72 hours after each trial in order to obtain their individual muscle soreness ratings. Participants were asked to analyze their muscle soreness on a scale of 1-10. Participants were instructed on how to exactly quantify their muscle soreness utilizing a pain scale ranging from 1 (no pain) to 10 (worst pain that the individual has ever experienced).

Participants completed the second trial on the same trail seven days after the first trial at approximately the same time of the day. The same pre- and post-test procedures were followed for each trial. However, prior to the start of the second trial, the participants were outfitted with the CG.

STATISTICAL ANALYSIS

Data were analyzed using SPSS (version 21.0; IBM Corporation, New York, USA). Descriptive data were reported as mean and standard deviations for the total sample. Due to non-normality of the data, differences in mean scores were determined *via* a series of Wilcoxon signed rank tests for the whole, ascent and descent portions of the test. Calculations to determine percentages of change between pre- and post-testing sessions, as well as trial one and two were also performed. *A priori*alpha levels were set at $p \leq 0.05$.

RESULTS

The results section is split into three separate sub-sections. The first sub-section provides the physiological outcomes for all participants. The second sub-section describes the analysis of the performance measures of all participants between both trials. The third sub-section details the statistical differences between trials for post exercise pain/recovery ratings. Only data that was found to be statistically significant, or approaching statistical significance (i.e., p=0.06 or less), are detailed within each table.

Physiological Data

All physiological data were collected *via* the Zephyr Bioharness 3™. Mean and standard deviations for each variable and trial are detailed in Table 1. Between the two 7 km trials, significant differences between trial 1 (control) and trial 2 (CG) were found in physiological load (p=0.04); training load (p=0.01); average physiological intensity (p=0.05); and estimated caloric expenditure (p=0.02) (Table 1).

Table 1. *Differences between Time Trials*

Variable Measured	Trial 1 (Control) (Mean ± SD)	Trial 2 (CG) (Mean ± SD)	Significance
Physiological load (au)	496.79 ± 98.28	454.33 ± 70.49	p=0.04*
Training load (au)	397.56 ± 47.15	374.11 ± 38.37	p=0.01*
Average physiological intensity (au)	37.53 ± 1.77	7.03 ± 1.59	p=0.05*
Estimated caloric expenditure (kcal)	1157.90 ± 249.10	1092.70 ± 196.43	p=0.02*

*Statistically significant at $p \leq 0.05$

Due to each trial consisting of an ascent and descent portion, analysis of each portion was completed separately. During the 3.5 km ascent portion of Trial 1 (control) and Trial 2 (CG), significant differences were found between trials in estimated caloric expenditure (p=0.04) (Table 2). Furthermore, during the 3.5 km descent portion of Trial 1(control) and Trial 2 (CG), significant differences were discovered between trials in estimated core temperature (p=0.04); physiological load (p=0.01); mechanical load (p=0.01); average physiological intensity (p=0.008); average mechanical intensity (p=0.02); and estimated caloric expenditure (p=0.05) (Table 3).

Table 2. *Ascent Time Trial Only (3.5 km)*

Variable Measured	Trial 1 (Control) (Mean ± SD)	Trial 2 (CG) (Mean ± SD)	Significance
Estimated caloric expenditure (kcal)	744.78 ± 150.28	714.66 ± 128.79	p=0.04*

*Statistically significant at $p \leq 0.05$

Table 3. *Barr Trail Time Trial: Descent Only (3.5 km)*

Variable Measured	Trial 1 (Control) (Mean ± SD)	Trial 2 (CG) (Mean ± SD)	Significance
Estimated core temperature (°F)	102.58 ± 1.36	102.01 ± 0.98	p=0.04*
Physiological load (au)	405.55 ± 105.01	364.00 ± 71.44	p=0.01**
Mechanical load (au)	175 ± 43.74	152.11 ± 32.66	p=0.01**
Average physiological intensity (au)	187.89 ± 24.14	174.11 ± 20.68	p=0.008**
Average mechanical intensity (au)	7.7 ± 1.49	7.0 ± 1.44	p=0.02*
Estimated caloric expenditure (kcal)	405.56± 105.01	364.00 ± 71.44	p=0.05**

*Significance at $p \leq 0.05$
** Significance at $p \leq 0.01$

Performance Measures

Significant differences were found between average vertical jump height (p=0.04) between trials (Table 4). This was indicative of a 4.53% improvement in average vertical jump height when wearing the CG. Additionally, it was also found that the total peak anaerobic power output (PAPw) generated was significantly greater (p=0.04) during the second pretesting session in which the CG were worn.

Table 4. *Power Measures: Differences between Pre-tests*

Variable Measured	Trial 1 Pre-test (Control) (Mean ± SD)	Trial 2 Pre-test (CG) (Mean ± SD)	Significance
Average vertical jump height (cm)	54.33 ± 9.73	56.79 ± 9.06	p=0.04*
PAPw (watts)	3103.96 ± 619.76	3166.61 ± 581.50	p=0.04*

Peak power in watts (PAPw)=total peak anaerobic power output
*Statistical significance at $p \leq 0.05$

Significant increase was found between the total isometric strength produced during the isometric mid-thigh pull prior to each time trial, with the CG treatment showing better performance on average (p=0.03).This represents an increase in the total amount of weight lifted by 5.37% while wearing the CGs (Table 5).Additionally, significant differences were found between the total (p=0.03) isometric strength measurements collected for Trial 1(control) and Trial 2(CG) with the average pretest scores approaching significance at (p=0.051). This represents a 7.62% increase in performance while wearing the CGs. There was also significant difference between the total isometric strength between each pretest (p=0.05).This represents an increase in the total amount of weight lifted by 5.40%.

Table 5. *Isometric Strength: Differences between Pre-tests*

Variable Measured	Trial 1 Pre-test (Control) (Mean ± SD)	Trial 2 Pre-test (CG) (Mean ± SD)	Significance
Average isometric strength (kg)	187.87 ± 29.5	202.19 ± 31.54	p=0.051*
Total isometric strength (kg)	563.64 ± 88.48	606.56 ± 94.63	p=0.03*

*Significance level at $p \leq 0.05$

Post Exercise Pain Scale Ratings

While no significant mean score differences were found between trials in post exercise pain scale ratings at 24 hours, significant differences were observed at 48 hours (p=0.01) and 72 hours (p=0.038) post event with significantly less pain reported after the trialsin which the CGs were worn.(Table 6).

Table 6. *Pain Scale Differences between Trials*

Variable Measured	Trial 1 (Control) (Mean ± SD)	Trial 2 (CG) (Mean ± SD)	Significance
24 hour post event	7.0 ± 4.6	6.0.± 3.3	p=0.06
48 hour post event	3.39 ± 1.3	1.33 ± 0.7	p=0.007*
72 hour post event	1.44 ± 0.5	0.7 ± 0.7	p=0.038*

*Significant level at $p \leq 0.05$

DISCUSSION

The aim of this pilot study was to investigate the influence of lower body compression garment on selected physiological, perceptual, and performance measures while traversing extreme terrain at altitude. Few studies have examined the effects the CGs have on trained trail runners.[9,14] This is the first known study to examine the effects that CGs have on physiological, performance, and perceptual measures while navigating steep off-road terrain at altitude in non-competitive trail runners. These results may be significant for those recreational and competitive athletes that participate in training and events performed over similar terrain. Furthermore, reduced levels of pain in the hours following such activity may allow athletes to train more frequently and at a higher intensity.

Our findings did not reveal any statistically significant differences in time-to-completion between Trials 1 (control) and 2 (CG). These results are similar to previous studies where CGs did not produce any performance enhancements in sub-maximal endurance runs.[9,14] In the current study, however, the lack of significance may be due to a low sample size and one participant who performed significantly worse during the second trial. Interestingly, seven of the nine participants improved their completion times while wearing the CGs by an average of 3.25%. Since, all participants were familiar with this trail, it is unlikely that this improvement was due to a learning effect.

For the ascent portion, four of the nine participants improved their ascent time while five were marginally slower. Remarkably, it was found that eight of the nine participants actually improved their time during the descent portion by an average of 6.29%.Thus, the descent portion for the second time trial appears to have accounted for the improvement in completion times between trials. This difference in time to completion, despite a slightly greater average group time on the ascent portion (0.56%), may also be explained by the observed reductions in physiological and mechanical load, as well as the average physiological and mechanical intensity while wearing the CGs.

Previous authors have suggested that the descent portion of the trial can lead to greater muscle damage due to the repetitive eccentric loading while running downhill.[10] This is consistent with results from a similar study where participants were required to walk downhill for 30 minutes on a treadmill.[19] These researchers discovered that the CGs may have altered the inflammatory response of the working muscles allowing the muscles to repair faster.[19] The CGs could lead to a reduced amount of muscle oscillations experienced by the participant while controlling the repetitive eccentric loading of the lower body during the descent portion of the trial.[13] This rapid recovery from the repeated eccentric loading in the muscle could also explain the reductions in the physiological parameters since less energy would be required with improved efficiency.

Previous research has speculated that graduated CGs may improve circulatory function during low to moderate activity as well as reducing energy expenditure due to the pressure gradient which has in turn been suggested to improve both venous return and blood flow.[6,15] Therefore, CGs may produce an improved ability to conserve high-energy phosphates for subsequent short bursts of energy, and increase the clearance of metabolic waste products, leading to an increased repeated performance at high speeds.[3,6] However, significant differences between the first (control) and second (CG) time trials were discovered in several areas. It was observed that participants experienced significant reductions in estimated physiological and training load, average physiological intensity, and caloric expenditure while wearing the CGs. Our results showed that that there was no improvement in time to completion, but there was a significant decrease in the physiological cost and caloric expenditure while wearing CGs. These findings are in accordance with other studies that reported a decreased physiological cost while performing submaximal endurance exercise when wearing CGs.[7,16] The decrease of physiological demand while exercising is extremely desirable, as this may lead to an increase in exercise capacity and muscle efficiency.[6,17] In addition, previous studies have reported that CGs provided participants with increased kinesthetic and proprioceptive awareness leading to an increase in running efficiency, resulting in a decrease in the metabolic cost of exercise.[16,17] The combination of the lower metabolic energy cost and the possible ergogenic effect exerted on the exercising limbs may explain the decrease in caloric expenditure during sub-maximal exercise.[22]

For recreational and athletic competitors, it is not only the ability to express power, but also sustaining it may ultimately determine success. In this regard, there was no statistically significant differences between Trial 1 (control) and Trial 2 (CG). This is in agreement with previous studies that also reported no performance enhancements in CMJ between CGs and classic athletic wear.[11,14,22,23] However, the pre-test sessions for each time trial revealed significant differences in average jump height (4.53%) when wearing the CGs. This in in accord with other studies that also reported an increase in jump height while wearing CGs.[17] Moreover, while statistically insignificant, it is interesting that six of the nine participants in the current study achieved their greatest vertical jump heights during the pre-testing trials while wearing the CGs. Additionally, analysis for the total PAPw for all countermovement jumps during the pre-testing sessions was greatest while wearing the CG. This result is in agreement with the study conducted by Kraemer et al[23] where results showed that CGs increased vertical jump height in pre-test conditions.[23] Although the exact mechanism that CGs use to produce optimal performance enhancements is still relatively unknown, the increase in jump height and power production could be due to a combination of the physiological recoil from the CMJ in the muscle and the elastic component in the CGs.[1,6,8] This could theoretically improve proprioception and lead to an increase in power output.[11]

Isometric strength in this study was measured using a leg-back dynamometer. Results from the current study show that the average isometric strength between pre-test sessions was significantly greater (7.6%) while wearing the CGs. Participants also significantly improved on the total amount of isometric force produced (5.37%) during the second pre-testing session in which the CG was worn. Moreover, while not statistically significant, it is noteworthy that a greater total amount of isometric force (3.01%) was also produced in the post-testing session in which the participants wore CGs. A recent study by Vercruyssen et al[14] examined the effect of CGs on off road, trail-running performance in a race setting. Following the 15.6 km off-road race, the researchers found no statistically significant difference in maximal voluntary contraction values following a 15.6 km trail run between participants who wore CGs and regular athletic apparel.[18] These findings suggest that the strength levels following the fatiguing endurance protocol were well maintained.[14] The primary difference between this current study and that of Vercruyssen et al[14] is that the total distance covered was over 8 km shorter, and our participants were not high-level runners. Also, the physiological demand was lower when the participants were wearing the CGs. This increase in physiological efficiency could have led to the non-significant increase in isometric strength following the submaximal endurance exercise. Thus, based on these results, it is evident that an overall greater magnitude of force was produced when wearing the CGs. This may have practical significance, especially during use of situations in which sustained output of force is required.

CONCLUSION

The purpose of this study was to investigate the effects that CGs on the physiological, perceptual, and performance measures following traversing austere conditions at a relatively higher altitude. The CGs in this study did not produce any significant performance improvements following a 7 km time trial over uneven terrain. However, the CGs decreased the amount of physiological load, training load, and average physiological intensity and estimated caloric expenditure when compared to loose fitting, or regular, athletic clothing.Due to the limited knowledge of the mechanisms underlying the action of CGs, more research is needed to gain deeper insights on the ergogenic effect of CGs following submaximal exercise. Further studies should also examine the use of compression garments in the tactical population, as these individuals often need to cover austere terrain over long-distances and maintain strength and power are essential to mission success.

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CONFLICTS OF INTEREST

None of the authors have any conflicts of interest.

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