EFFECTS OF EIGHT WEEKS OF

VITAMIN D SUPPLEMENTATION ON PHYSICAL

PERFORMANCE IN A PHYSICALLY ACTIVE POPULATION

by

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ABSTRACT

Context: Vitamin D deficiency is common in the general and athletic population. It is indicated that vitamin D may play an important role in muscle function and physical performance. **Objective:** The purpose of this investigation is to determine if an eight-week supplementation of 50,000 IU of vitamin D_3 will reverse deficiency in a physically active population. A secondary purpose of this investigation is to determine if vitamin D_3 supplementation will increase musculoskeletal performance abilities in a 40-meter sprint, 1 RM bench press, and vertical jump height. **Design:** Double-Blinded, Randomized Controlled Clinical Trial **Setting:** Laboratory **Participants:** Twenty-nine physically active men (n=11) and women (n=18) (age =23.21 ± 1.52 yrs, weight =70.66±14.23 kg, height=171.18±9.03 cm) from Texas State University volunteered to participate in the investigation. **Interventions:** Subjects were randomized into two groups receiving either 50,000 IU of vitamin D_3 for eight weeks or a placebo pill. Pre-supplementation serum 25(OH)D levels were measured to determine deficiency. Physical performance measures (1-RM bench press, 40 meter sprint, and vertical jump height) were assessed pre-supplementation and post-supplementation. Subjects met with the investigator one time each week for eight weeks to receive 50,000 IU vitamin D_3 capsule or placebo capsule. Vitamin D blood serum levels were measured again at the end of the investigation's eight-week supplementation period. **Main Outcome Measures:** The main outcomes measured in this investigation were serum 25(OH)D levels, 1-RM bench press, 40-meter sprint, and vertical jump height.

Results: Total serum 25(OH)D concentration significantly increased in the vitamin D supplementation group after eight weeks of supplementation with 50,000 IU of vitamin D ($p<0.00$). At baseline testing 66% of the participants were vitamin D deficient. After eight weeks of supplementation all participants in the treatment group reached optimal values above 50ng/ml. There were no significant differences between the two groups in any of the performance tests measures over the eight week supplementation period (1RM bench press, $p=0.583$; vertical jump height, $p=0.820$; 40-meter sprint, $p=0.969$).

Conclusions: Eight weeks of 50,000 IU of vitamin D supplementation one time per week significantly increased vitamin D serum levels and reverse vitamin D deficiency in a young, physically active population. Supplementation of vitamin D for eight weeks had no effect on physical performance measures.

Key Words: ergogenic aid, muscle function, physically active, nutritional supplementation

CHAPTER I
INTRODUCTION

Many factors effect athletic performance including genetics, nutrition, and the environment. A combination of these factors can also influence the levels of serum vitamin D (25(OH)D) available for use in the body. The primary source of vitamin D is solar ultraviolet-B radiation from direct sunlight.[2] However, some vitamin D can be obtained through milk, fortified breads and cereals, and fatty fish such as salmon and sardines.[3-5] Available sources of vitamin D are limited to decreased exposure to sunlight, use of sunscreen, melanin content of the skin, clothing covering the body, and access to food sources.[6]

Research has shown over 60% of children and 75% of adults in the United States alone suffer from vitamin D insufficieny.[1] Not only is vitamin D deficiency an issue in the United Stated, but it is a worldwide epidemic. Low levels of vitamin D are connected to many health related issues including low bone density, cancer, heart disease, and increased risk for infection.[1] Along with being related to health issues, vitamin D plays an important role in protein synthesis, cell proliferation, and cell differentiation.[2] Vitamin D is the main biding site for, the secosteriod hormone, calcitriol whose main functions are to signal gene transcription and regulate the activity of neurons, muscles, bones, heart, and lungs.[7] Vitamin D also plays an important role in regulating the blood levels of calcium supporting the functions of muscle contractions and nerve conduction.[2,8] Athletes have the greatest musculoskeletal stress, which could be compromised by vitamin D deficiency.

Vitamin D has a large influence on the function of skeletal muscles and neurons, and an important role in physical performance. Past research has shown there is a high prevalence of vitamin D deficiency, and vitamin D's effect on physical performance in the young and the old[9-12] The importance of vitamin D on muscle function was first discovered in young children with rickets and older patients who suffered from osteomalacia.[9] The discovery of muscle weakness, generalized pain, and hypotonia in children led to research on the supplementation of vitamin D to reverse these abnormalities. Further investigations have examined the effects of supplementation on reaction time, balance, and neuromuscular function in older adults.[10-17] Several studies found that vitamin D supplementation in older adults was able to improve reaction time, balance, and neuromuscular function.[10- 17]

Extensive research has investigated the effects of vitamin D on neuromuscular function in older adults, but limited research exists on the supplementation of vitamin D to help improve physical performance in athletes.[10-17] Recent research has established that many athletes have vitamin D deficiency and insufficiency including many dancers and gymnasts.[1,18,19] In Europe, research has been done to determine that many professional or elite athletes across a variety of sports, are vitamin D deficient.[2,20-23] In the United States, the prevalence of vitamin D deficiency was examined in over 200 collegiate athletes and found nearly 70% did not meet adequate levels.[24] Throughout the world, over a wide variety of age groups and athletic levels, recent research has shown vitamin D deficiency is prevalent in athletic populations.[1,2,18-24]

However, little research has been done to determine the effects of supplementation on athletes or physically active individuals to determine if vitamin D can improve physical performance, muscle function, and return athletes to a normal serum vitamin D level. Four studies supplemented athletes with varying levels of vitamin D for varying lengths of time and all found that serum vitamin D levels improved.[5,19,24,25] Serum vitamin D levels improved with no consistency on the adequate amount of vitamin D that should be supplemented.[5,19,24] In addition, research of prescribed dose of vitamin D and duration of supplementation improvements in physical performance is equivocal. One investigation on ballet dancers found that isometric strength and vertical jump were improved with vitamin D supplementation.[19] However, two other studies found no improvement in physical performance for athletes who were supplemented with vitamin D.[25,26] These inconsistencies in the research show that there is evidence lacking to determine if vitamin D supplementation is an effective treatment to improve physical performance in a physically active population. Although it cannot be determined if physical performance can be enhanced with vitamin D supplementation it is clear that vitamin D deficiency is an epidemic among athletes and an adequate dose amount needs to be determined to return athletes to normal serum levels of vitamin D.

Problem Statement

Recent research has established that a high percentage of athletes suffer from vitamin D deficiency or insufficiency. While a large amount of research has been done to look at the effects of vitamin D supplementation on an elderly population and in adolescents, research is lacking to determine the effects of supplementation on a physically active, young adult population. When athletes are lacking vitamin D they are at an increased risk of suffering from stress fractures, impaired muscles function, and immune dysfunction. Along with an increase in injury risk, athletic performance may be limited from an insufficient amount of vitamin D. Therefore, the purpose of this investigation is to determine if an 8-week supplementation of 50,000 IU of vitamin D_3 will reverse deficiency/insufficiency in a young, physically active population. A secondary purpose of this investigation is to determine if vitamin D supplementation will increase a physically active person's musculoskeletal performance ability in a 50-meter sprint, 1 RM bench press, and vertical jump.

Hypothesis

1. The treatment group, receiving 50,000 IU of vitamin D per week, will have a significant increase in blood serum levels at the end of the 8-week supplementation. The placebo group will not see a significant increase in blood serum levels of vitamin D.
2. The treatment group will see a significant increase in vertical jump height following the 8-week supplementation. The placebo group who will have no significant improvements in vertical jump height.
3. The treatment group will have a significantly faster 40-meter sprint time following the 8-week supplementation. The placebo group that will see no significant decrease in 40-meter sprint time.
4. The treatment group will have a significantly higher 1 RM following the 8-week supplementation. The placebo group that will see no significant improvements in 1RM bench press.

Operational Definitions

Vitamin D Deficiency - 25(OH)D levels less than $32 ng/mL^{-1}$
Optimal vitamin D levels- 25(OH)D greater than $50 ng/ml^{-1}$

1RM- The maximum amount of weight that can be lifted one time

Physically Active- A person who performs moderate-intensity aerobic exercise for 30 minutes 5 days per week or 20 minutes of vigorous activity three days per week as defined by the ACSM standards.

Delimitations

As with any investigation, there are delimitations that may affect the collection and interpretation of the data. These delimitations include:

1. The subjects are between the ages of 18 and 30 years old.
2. Subjects will only be included in the investigation if they take part in moderate intensity exercise for 30 minutes, five days per week or vigorous activity for 20 minutes, three days per week.
3. The type of physical activity the subjects partake in during the supplementation period is not controlled.
4. The diet of the subjects is not restricted or controlled during the investigation.
5. Supplementation will only be given to the subjects for an 8-week duration.

Limitations

This investigation has limitations that may affect data collection and interpretation. The limitations include:

1. The results of this investigation cannot be generalized to an adolescent or geriatric population.
2. This investigation cannot be generalized to sedentary (does not follow ACSM guidelines for physically active) or athletic population.

3. The results of this investigation only determine improvements in power activities and not endurance activates of physical performance.
4. This investigation cannot be generalized to supplementation on a variety of vitamin D sublevels (D_1, D_2) and periods that are longer or shorter than 8 weeks in duration.
5. This investigation is limited in determining the effects a restricted or controlled diet may have on improvements of vitamin D serum levels. Research funding limited the opportunity to provide controlled diets.

<u>Assumptions</u>

The assumptions made for this investigation include:

1. The subjects will show up each week at their designated time to receive their supplements.
2. The subjects are not taking any other supplements such as a multi vitamin during the investigation.
3. The subjects do not alter their work out routine during the investigation. The subjects will continue to workout at moderate-intensity aerobic exercise for 30 minutes 5 days per week or 20 minutes of vigorous activity three days per.
4. The subjects will give 100 percent effort during both pre-testing and post-testing of physical performance.
5. The subjects will fill out all questionnaires to the best of their knowledge.

<u>Significance of Investigation</u>

This investigation will further evaluate the amount of vitamin D that should be supplemented in order to return physically active young adults from deficiency to having an adequate serum level of vitamin D (25(OH)D). The study will also further investigate the effects vitamin D has on physical performance. The results of this investigation may further show that increased vitamin D levels help to improve physical performance and overall health of physically active individuals. Results from this investigation will add to the limited amount of research available regarding vitamin D supplementation on athletic and physical performance from vitamin D deficiency.

CHAPTER II
LITERATURE REVIEW

Vitamin D is a fat soluble vitamin mainly produced in the skin from exposure to ultraviolet radiation.[7] Exposure to ultraviolet radiation produces 80-100% of the bodies required vitamin D, but vitamin D can also be gained from food sources.[4] However, a limited number of food sources have high concentrations of vitamin D. These food sources include fortified milk, cod liver, and fatty fish such as salmon and sardines.[4] Since food sources are limited, the average American diet supplies little of the 4,000-5,000 IU used by the body per day.[28] Lactose intolerance is another risk factor since a large portion of vitamin D from the diet comes from fortified milks. Along with being limited by diet vitamin D is also limited by indoor activities, sunscreen use, time of day, increased age, latitude, season, and skin coloration.[28] Over 75% of whites and 90% of African American/Latinos are vitamin D deficient in the United States alone.[28] The prevalence of vitamin D deficiency is alarming due to its role in many physiological functions, specifically muscle function, in the body.

Vitamin D's Role in Muscle Function

Vitamin D is known for its role in the maintenance of calcium and phosphorus homeostasis.[7,27] However, empirical evidence has established its role in the regulation of other cell functions, including its effect on muscle cells.[7] Vitamin D_3 (cholecalciferol) is produced in the dermis of the skin, converted to 25-hydroxyvitamin D (25(OH)D) in the liver, and ultimately converted to calcitriol, the active form of vitamin D, in the kidneys.[7] Calcitriol is a secosteriod hormone that is transported in the blood.[7] Once converted to calcitriol, there are over 1,000 genes that are responsive to the effects of vitamin D.[28] The genes response to vitamin D affect protein synthesis and gene transcription which influence muscle strength, muscle size, reaction time, balance, coordination, endurance, and inflammation.[28] Vitamin D activity is facilitated and transported by 1,25 $(OH)_2D$ binding to the vitamin D receptor (VDR), and in 1985 VDRs were discovered in muscle, indicating vitamin D plays an active role in muscle function.[7]

Empirical evidence has shown how vitamin D directly affects muscle function. The VDRs are part of the steroid hormone family and are important for mRNA transcription, protein synthesis, increased calcium uptake, and muscle fiber differentiation.[7] Studies have discovered 1,25 $(OH)_2D$ enhances transcription in proteins.[7,27,30] An important protein to muscle function, is IGFBP-3.[7,30] This protein is part of the insulin-like growth factor protein family and helps bind insulin-like growth factor-1 (IGF-1).[7,27] Insulin-like growth factor-1 initiates proliferation, differentiation, and hypertrophy of muscle tissue.[27,30] IGF-1 plays an important role in muscle regeneration through one of its three isoforms.[27] The three isoforms of IGF-1 mediate muscle regeneration by differentiating muscle cells into myotubes, promoting stem-cell muscle regeneration, and controlling local tissue repair.[27]

While IGFBP-3 plays an important role in muscle function, calcium may play an even larger role. Vitamin D effects muscle function through both transcription of proteins regulated by calcium and total body levels of calcium.[4] Research has shown that $1,25(OH)_2D$ helps to regulate calcium uptake by controlling the activity of calcium pumps in the sarcoplasmic reticulum and the sarcolemma.[29] Which in turn control relaxation and contraction of muscles.[29] The need for calcium is also important because of its binding property with calmodulin.[29] Calmodulin is a protein dependent on

1,25$(OH)_2$D and helps to regulate muscle contraction.[29] Overall, vitamin D, 1,25$(OH)_2$D, helps to modulate calcium uptake which plays a significant role in muscle function due to its effects on contraction and relaxation of muscles.[4,7,29]

In addition to affecting IGFBP-3 and calcium uptake, vitamin D plays an important role in phosphate metabolism.[29] Exposure to 1,25$(OH)_2$D helps to increase phosphate uptake in the sarcoplasmic reticulum and accumulation in the cells.[4, 29] An increase in phosphate leads to an increase in the ability for ATP production and increased protein synthesis.[4] The ATP is needed for metabolic functions of the muscle.[29] Through increased phosphate metabolism there is an increase in available energy for the cell which in turn leads to greater muscle performance.[4,29]

Vitamin D and Neuromuscular Function in the Elderly

The role of vitamin D in skeletal muscle function and physical performance has been extensively researched in an elderly population. Numerous studies have looked at the effects vitamin D serum levels and vitamin D supplementation has on neuromuscular function in the elderly.[10-17] These studies have found vitamin D is directly related to improved balance, reaction time, muscle strength, and neuromuscular function in an elderly population.[10-17] Dhesi et al. conducted an investigation to assess the effects of vitamin D supplementation on neuromuscular control in older people who fall.[10] The investigation included 139 subjects who were older than 65 years old, had a history of falls, and had 25(OH)D levels less than 12 ug/1. The intervention group received 600,000 iu of ergocalciferol through a single intramuscular injection, while the placebo group received 2 ml of normal saline.[10] The neuromuscular parameters assessed in the investigation included assessment of lower limb function by timing activities of daily living (50ft walk, rising from a chair and walking, ascent and decent of stairs), choice reaction time, postural sway, and quadriceps strength.[10] Dhesi et al. found vitamin D levels had significantly improved in the intervention group at the 6 month follow- up. Functional performance times decreased in the placebo group, but significantly improved in the intervention group. There were also significant changes in reaction time and postural sway in the intervention group. Although there were neuromuscular changes observed in functional performance time, reaction time, and postural sway, there was no improvement in quadriceps muscle strength due to vitamin D supplementation. This investigation shows vitamin D supplementation does improve neuromuscular function in an elderly population.[10]

Although Dhesi et al. were not able to find improvements in muscle strength in an older population related to vitamin D supplementation, studies conducted by three other authors found improvements.[10, 11,14,16] A double-blinded, randomized controlled trial studied 122 elderly women and the effects vitamin D supplementation had on musculoskeletal function.[11] The treatment group (n=62) received 1200 mg calcium and 800 IU vitamin D_3 every day for 12 weeks.[11] While the control group received 1200 mg of calcium.[11] The subjects in the experimental group showed significant improvements in vitamin D serum levels and in musculoskeletal function.[11] Musculoskeletal function was measured by taking isometric knee flexor and extension strength, grip strength, and timed up and go test.[11] Zamboni et al. also measured isometric knee extension strength along with arm extension strength to determine musculoskeletal function in relationship to vitamin D levels in an elderly population.[16] There were 175 women and 94 men ranging in age from 68-75 years old included in the investigation.[16] No supplementation intervention was performed in this investigation, but the relationship between vitamin D serum levels and neuromuscular function was assessed.[16] The investigation found that in women who had inadequate levels of 25(OH) there was a significant association with decreased muscular strength.[16] Zamboni et al.'s investigation shows that vitamin D plays an important role in muscle strength in an elderly population.[16] Another investigation performed by Pfeifer et al. examined vitamin D status and its relationship to trunk muscle strength, body sway, and falls in 237 postmenopausal women.[14] A significant correlation was found in this investigation between decreased muscle strength and low vitamin d levels in older women. Again, indicating that vitamin D plays an important role in muscle strength in an elderly population.[14]

In addition to finding a strong correlation between vitamin D serum levels and muscle strength in older women, Pfeifer et al., also found a relationship to body sway. Decreased vitamin D levels correlated to an increase body sway.[14] To further support these findings another investigation done by Pfeifer et al. examined the effects of vitamin D supplementation on body sway in elderly women.[13] Included in the investigation were 148 women with a mean age of 74 years old and vitamin D levels below 50 nmol/liter. The subjects received either 1200 mg calcium plus 800 IU of vitamin D or just 1200 mg calcium every day for 8 weeks. At the end of the eight weeks vitamin D levels and body sway were reevaluated finding that vitamin D and calcium helped to reduce body sway. Therefore, there was an improvement in neuromuscular function with vitamin D supplementation.[13] To further support these findings a investigation done by Lips et al. found that a weekly dose of 8,400 IU of vitamin D reduced sway when compared to the placebo treatment.[15] There was a total of 226 patients who were older than 70 years included in the investigation . The intervention group (n=114) received 8,400 IU of vitamin D for 16 weeks, while the control group (n=112) received a placebo supplement. In addition to body sway, neuromuscular control was tested by measuring short physical performance battery (SPPB), which measures standing balance, gait speed, and time to sit and rise from a chair five times. There was no difference found between treatment groups for SPPB measures showing 8,400 IU of vitamin D a week has no effect on functional neuromuscular outcomes in an older population.[15]

While, Lips et al. did not find any significant improvements in functional neuromuscular outcomes with vitamin D supplementation in an elderly population two other studies have found a significant relationship.[12, 15, 17] Bischoff-Ferrari et al. found higher concentrations of vitamin D are associated with better lower-extremity function.[12] In this investigation 4,100 adults between the ages of 60 to 90 years old were assessed for vitamin D concentrations, timed eight foot walk test, and a repeated sit-to-stand test.[12] Higher levels of vitamin D were significantly correlated with improved walking time and sit-to-stand measures.[12] Gloth et al. also found functional improvements in patients who received vitamin D replacement.[17] Thirty-two patients who were vitamin D deficient received a vitamin D replacement that ranged from 400 IU to 100,000 IU per day. At initial evaluation and a one-month follow up the Frail Elderly Functional Assessment, which detects small changes in functional improvements in the elderly, was performed. A significant relationship was found between improved vitamin D levels and improvement in function.[17] Overall, neuromuscular function, balance, and strength improvements can be seen with vitamin D supplementation and higher levels of serum vitamin D in an elderly population.[10-17]

Vitamin D Status in Athletes

Recent research, over a wide variety of athletic events, has established vitamin D deficiency is an epidemic in athletes.[1,3] Dancers and gymnasts were some of the first athletes vitamin D deficiency was discovered in.[1,18,21] In an investigation performed by Lovell[21] vitamin D status (serum 25(OH)D) and dietary calcium intake were assessed in young gymnasts. Eighteen female gymnasts between the ages of 10-17 years old took part in the investigation.[21] Lovell found that 15 of the 18 gymnasts had vitamin D serum levels below 75 nmol/L and 6 had levels below 50 nmol/L showing a high percentage of gymnasts are vitamin D deficient and at an increased risk for injury.[21] Another investigation was done to assess the vitamin D status of professional ballet dancers and compare their vitamin D levels between summer and winter months.[18] Wolman et al. monitored the serum vitamin D levels of 19 ballet dancers, with a mean age of 26 years, for a six month time period.[18] Not only did the investigation look at vitamin D levels between seasons, but it also examined blood serum bone turnover markers and injury rates. During the winter months all 19 of the dancers were vitamin D deficient or insufficient, and during the summer 16 did not meet adequate vitamin D levels. However, there was a significant decrease in the number of soft tissue injuries and a decrease in bone turn over markers from winter to summer. The investigation conducted by Wolman et al. shows athletes, specifically dancers, are at a high risk for vitamin D deficiency.[18] To further support these findings a investigation performed by Constantini et al. found vitamin D deficiencies in dancers and other athletes.[1] Data on 98 athletes and dancers, with a mean age of 14.7 years, was pulled from medical records.[1] The extraction of data showed that 73% of the athletes were vitamin D insufficient. The highest incidence of vitamin D deficiency was among athletes who participated in indoor sports; 94% of basketball player, 94% of dancers, and 67% of Tae Kwon Do fighters were found to have vitamin D insufficiency.[1] Studies conducted on indoor athletes such as dancers, gymnasts, and basketball players show athletes have a high incidence of vitamin D insufficiency.[1,18,21]

Evaluation of vitamin D insufficiency has not only been conducted on young gymnasts and dancers, but has continued into college level athletics.[3,24] In one investigation vitamin D status relative to diet, lifestyle, injury, and illness was assessed.[3] Vitamin D concentrations and injury rates were measured in 41 college athletes during the academic year.[3] Halliday et al. discovered vitamin D levels changed depending on the season. In the fall 75.6% of the athletes had optimal levels, in the winter only 15.2% had optimal levels, and in the spring 36% of the athletes had optimal levels. The results from this investigation indicate a large number of college athletes in the winter and spring are vitamin D insufficient.[3] Another investigation looked at the prevalence of abnormal vitamin D levels in Division I NCAA athletes.[24] Serum 25(OH)D levels of 223 athletes were measured and a mean serum level of 40.1 ng/mL was reported. Of the total subjects screened 66.4% had sufficient vitamin D levels and 33.6% were vitamin D insufficient. While the number of athletes found to be vitamin D deficient was lower than reported in other studies still more than a third of the athletes were at increased risk for injury from vitamin D insufficicney.[24] The investigation was also able to indicate races of darker skin tones have a much higher risk for vitamin D insufficiency then white athletes.[24]

In the general athletic population, one investigation looked at vitamin D status in 19 endurance trained runners and triathletes between the ages of 19-45 years old.[31] The endurance athletes fasting blood samples of serum 25(OH)D determined that over 50% of the subjects did not have adequate vitamin D levels: 42% of the runners were deficient (25(OH)D <32 ng/mL) and 11% were insufficient (25(OH)D <20 ng/mL).[31] These results provide evidence that vitamin D insufficiency is not only an epidemic in indoor athletes like dancers, gymnasts, and basketball players, but also include outdoor athletes exposed to high levels of sunighlight.[31]

Findings of vitamin D insufficiency have not stopped in young or college athletes, but more recent research has found that a large number of elite and professional athletes are vitamin D insufficient.[20,22-23,32-34] A investigation conducted to determine the effects of vitamin D supplementation on elite Irish athletes found at baseline testing that 94% of the athletes were vitamin D insufficient.[22] While, these findings were during the winter months when vitamin D levels are expected to be lower it should be expected that elite athletes are receiving the best training and diets in order to meet the greatest demands of physical performance.[22]

Two studies have looked at vitamin D levels in professional Spanish athletes.[23,32] Garcia et al. conducted a investigation looking at serum 25(OH)D levels in 21 Spanish professional basketball players after winter time.[23] Twelve players (57%) were vitamin D deficient and only nine players had adequate levels with only two of them actually meeting the preferred or optimal serum level of >75 nmol/L. This investigation also showed that darker skinned players had a higher risk of being vitamin D insufficient.[23] Another investigation conducted in Spain analyzed serum samples from 408 elite athletes from 34 different sports.[32] Results from the investigation showed that 82% of the athletes were below optimum vitamin D levels. Of those below adequate serum 25(OH)D levels

45% were moderately deficient (<50nmol/L) and 6% had severe deficiency (<27.5 nmol/L).[32] Higher levels of vitamin D were found in athletes who trained outdoors compared to those training indoors.[32]

Two additional studies were conducted on professional soccer players from the English Premier and Poland to determine seasonal variation in vitamin D levels.[20,33] Twenty male soccer players from the English Premier League were used in an investigation to determine seasonal variation in vitamin D status.[20] The investigation found a decrease in vitamin D levels from summer to winter. During winter months over 65% of the soccer players were vitamin D insufficient (<50 nmol/L). Again this investigation found that players who were dark skinned had lower levels of vitamin D. There were similar findings of vitamin D insufficiency from an investigation conducted on Caucasian Polish professional soccer players.[33] In the summer months only 50% of the players met adequate vitamin D serum levels and in the winter months only 16.7% of the players were sufficient.[33]

A final investigation conducted on 93 Middle Eastern sportsmen continues to provide evidence that vitamin D insufficiency is an epidemic among athletes.[34] The investigation found that 91% of the subjects were vitamin D deficient; 58% had levels <10 ng/ml, 33% had serum levels <20 ng/ml, and the rest had levels <30 ng/ml.[34] All the athletes who took part in this investigation had darker skin again indicating that more serve vitamin D deficiencies occur among races with darker skin.[34]

Overall, the studies assessing vitamin D insufficiency in the athletic population prove there is an epidemic among athletes.[1,3,18,20-21,23-24,31-34] The research has also shown that vitamin D insufficiencies are more severe in winter months, in indoor athletes, and in darker skin tones.[1,3,18,20-21,23-24,31-34] There is an immediate need to determine the effects vitamin D has on athletic performance and adequate supplementation for athletes.

Supplementation Interventions for Muscle Function

While a large amount of research has been performed on vitamin D's effect on muscle function in an elderly population, little research has been done to determine how vitamin D contributes to muscle function and performance in an athletic or healthy population. Research supports that vitamin D insufficiency is an epidemic in an athletic population, but there has been little to no research conducted to determine how detrimental vitamin D insufficiency may be on athletic performance. Also, it needs to be determined if vitamin D supplementation can provide enhancement to physical performance or muscle function in athletes.

Athletic Population

The research on vitamin D levels, supplementation, and the overall effects on physical performance measures are limited and controversial. One investigation looked at the correlation between serum 25(OH)D levels to grip strength, balance, and swimming performance at varying speeds.[35] Eighty competitive adolescent male and female swimmers between the ages of 12-16 years old were included in the investigation. Serum vitamin D levels were measured through blood testing, grip strength was measured with a hand-held dynamometer, balance was measured with the unipedal stance test, and swimming was measured at 3 separate distances. The results of the investigation showed there was no significant correlation between serum vitamin D levels and any of the physical performance measures.[35] Overall, the investigation did not find that higher vitamin D levels lead to increased muscle function or physical performance.[35]

While no correlation was found between serum vitamin D levels and muscle function in Dubnov-Raz et al.'s investigation, vitamin D supplementation in elite ballet dancers improved physical performance measures.[19,35] Twenty-four elite classical ballet dancers were recruited from a touring ballet company.[19] Seventeen of the dancers received the intervention treatment of 2,000 IU of vitamin D_3 every day for four months. There were seven subjects in the control group and they received a placebo treatment. Serum 25 (OH)D levels, muscular strength, and muscular power was measured at the beginning and the end of the four-month treatment period. Muscular strength was measured through isometric contraction of the quadriceps and muscle power was measured by vertical jump height.[19] Significant improvements for isometric quadriceps strength and vertical jump height were reported for the intervention group after four months of vitamin D supplementation.[19] Wyon et al. found that vitamin D_3 supplementation can improve muscular function in athletes, specifically ballet dancers.[19]

In an investigation conducted by Close et al. it was also found vitamin D supplementation improves muscle function when compared to a control.[2] Sixty-one male athletes from four different sports (rugby, soccer, flat jockeys, and national hunt jockeys) and 30 male non-athletic controls were included in the study.[2] Athletes were given 5,000 IU of vitamin D_3 a day for eight weeks. Fasting venous blood samples of 25(OH)D and performance measures were taken at the beginning of the supplementation period and again at the end of the eight weeks. Performance measures included 1-RM bench press, 1-RM back squat, Illinois agility run, vertical jump test ,a 10 meter, and 30-meter speed test. Results from the investigation showed that the vitamin D supplementation increased serum levels from baseline, while no changes in serum levels were found in the control group. There was also an increase in 10-meter sprint times and vertical jump in the vitamin D supplementation group. Close et al.'s investigation shows 5,000 IU of vitamin D a day over an eight-week period is effective in improving serum 25(OH)D levels and specific physical performance measures.[2]

In contrast to the findings of the previous studies, two additional studies looking at vitamin D supplementation in athletes found no improvements in physical performance or muscle function.[25,26] One investigation randomly divided 30 club level athletes into three treatment groups; placebo, 20,000 IU vitamin D_3, and, 40,000 IU vitamin D_3 per week.[26] Athletes took the supplements for a 12 week time period.[26] Along with assessing vitamin D serum concentrations, muscle function was measured by 1 RM bench press, 1 RM leg press, and vertical jump. In all subjects who received vitamin D_3 supplementation, serum levels increased to greater than 50nmol/L at both the six week and 12 week evaluation.[26] However, there were no changes in muscle function in any of the groups.[26] Shaneley et al. also found no changes in muscle function after supplementing 33 high school athletes with 600 IU of vitamin D_2 (mushroom powder) over a six week time period.[25] The investigation found that supplementation of vitamin D_2 serum levels increased, but there was a decrease in vitamin D_3 serum markers. There was no improvement in muscle function measured by vertical and leg/back deadlifts.[25]

Overall, studies examining supplementation of vitamin D in athletes show conflicting evidence. Some studies have found improvements in muscle function, while others have not found improvements. However, it can be concluded that supplementing for six weeks or longer can return serum vitamin D levels to an adequate level.

General Population

Three studies have been conducted in the general population to examine vitamin D and its relationship on muscle strength and function.[36-38] Grimaldi et al. examined the relationship between serum 25(OH)D levels and muscle strength in 419 adults between the ages of 20-76 years old.[36] Muscle strength was measured by isometric hand grip strength, isometric knee flexion/extension strength, and isometric elbow flexion/extension. They found that higher vitamin D levels were significantly associated with increased muscle strength.[36] Another investigation, in the general population, examined the relationship between vitamin D status and muscle strength in 301 healthy Chinese adolescent girls.[37] Foo et al. measured 25(OH)D levels in blood plasma and compared these levels to handgrip muscle strength. They found girls who had adequate levels of vitamin D had increased grip strength compared to girls who were vitamin D deficient.[37] A third investigation by Ward et al. examined the correlation between vitamin D status and muscle function in 99 adolescent girls between the ages of 12-14 years.[38] It was found that girls who had higher serum levels of vitamin D had a greater jump velocity, jump height, more power, and scored higher on the Esslinger Fitness Index.[38] The three studies conducted in the general population show that vitamin D has a direct effect on muscle function.[36-38] Increased vitamin D serum levels correlate to improvements in muscle function.[36-38]

CHAPTER III
METHODOLOGY

The purpose of this investigation was determine if an eight-week supplementation of 50,000 IU of vitamin D would reverse deficiency in a young, physically active population. A secondary purpose of this investigation was to determine if vitamin D supplementation would increase a physically active person's musculoskeletal performance abilities in a 40-meter sprint, 1 repetition predicted maximum bench press, and vertical jump height.

Subjects

Twenty-nine, physically active, men (n=11) and women (n=18) from Texas State University were recruited for this investigation. The age range was selected because of their accessibility on campus. To be included in the investigation the subjects were physically active for at least the past year and currently taking part in moderate-intensity exercise for 30 minutes five days per week or 20 minutes of vigorous activity three days per week. Permission to conduct the investigation was granted by Texas State University Institutional Review Board, IRB #2015W9745. Each subject completed an informed consent before taking part in the investigation (Appendix A). Subjects also completed a demographic sheet and provide medical history before being included in the investigation. Demographic information on age, weight and was collected (age =23.21 ± 1.52 yrs, weight =70.66±14.23 kg, height=171.18±9.03 cm). Subjects were excluded from the investigation if they had a history of musculoskeletal injury or cardiovascular problems, which may have compromised the completion of the investigation protocol. Subjects were excluded from the study if they had a history of diabetes, thyroid dysfunction, or excessive weight loss. Exclusion form the investigation also occurred if the subjects were currently taking fish oil, a vitamin D supplement, or multivitamin containing vitamin D. Subjects were randomly assigned to one of two groups by drawing of a number out of an envelope. The treatment group received 50,000 IU of vitamin D_3, purchased from BioTech Pharmaceutical (Fayetteville, Arkansas), every week for 8 weeks. The placebo group received methycellulose purchased from Letco Medical (Decatur, Alabama). Subjects were asked to report to the laboratory wearing clothing they could exercise in and a short sleeved shirt that exposed their cubital vein for blood testing. They were also asked to refrain from having caffeine on the days of performance testing.

Procedures

Subjects who met inclusion criteria contacted the investigator, signed up for a time to take part in the investigation, and provided contact information.

Day 1: Determining vitamin D serum levels

1. Subject arrived at the testing site where they were informed of the procedures and expectations of the investigation. Testing on day one took approximately an hour.
2. Subjects completed the informed consent page agreeing to take part in the investigation (Appendix A).
3. Subjects completed a demographic information sheet including information about their age, weight, height, and sex (Appendix B).
4. Subjects completed a medical history questionnaire (Appendix C).
5. Subjects completed a vitamin D consumption questionnaire adopted from Halliday et al..[3] (Appendix D).

6. Venous blood samples to assess vitamin D serum levels were collected from the cubital vein. A total of 8ml of blood was collected in a standard red top tube.

Day 2: Pre-testing of physical performance measures

Following the collection of blood and completion of paperwork on day one the participants returned 24 hours later on day two for collection of pre-test physical performance measures. Testing on day two took between 1-1.5 hours.

1. Subjects were randomly allocated to the treatment group or placebo group by drawing a number out of an envelope.
2. Subjects performed a five-minute warm up and five minutes of stretching of their choice.
3. Baseline measurements were collected for physical performance measures. There was randomization of testing for each subject and the subjects received five minutes of rest between each activity (NSCA standard).[40]
    a. Vertical Jump height was assessed with the jump and reach method.
    b. Muscular strength was assessed by testing estimated 1 RM on the bench press through the standards established by the NSCA.[40]
    c. 40-meter sprint timed via Brower electronic timing system (Draper, Utah).
4. After all testing was completed subjects received the first week's supplement.

Weeks 2-8

1. Each week on their designated day the subjects met with investigator to receive the supplements for that week. Weekly meetings to receive supplementation took approximately 10 minutes.

Week 9- Posttest measurements

1. The day after taking their final supplement subjects returned to the research laboratory for post-test measures. This testing session lasted approximately one and a half hours.
2. Subjects performed a five minute warm up and five minutes of stretching of their choice.
3. Measurements were collected for physical performance measures. There was randomization of testing for each subject, and the subjects received five minutes of rest between each activity.
    a. Vertical Jump height was assessed with the jump and reach method.
    b. Muscular strength was assessed by testing estimated 1 RM on the bench press through the standards established by NSCA.[40]
    c. 40-meter sprint time was measured via Brower electronic timing system (Draper, Utah).
4. After all performance testing was completed venous blood samples to assess post-supplementation vitamin D serum levels were collected from the cubital vein. They were collected within a two hour time frame from the pre-test.

<u>Measurements</u>

Measurements for all subjects were taken at the start of the treatment protocol and again at the end of the eight-week supplementation period. The same investigator collected all measurements on both occasions. The principal investigator collecting physical performance measures was blinded to the randomization of the subjects, making this a double blinded study.

Vitamin D Assessment

Non-fasting venous blood samples were taken from the cubital vein. Vitamin D remains stable in the blood indicating fasting or exercise have a limited effect on serum levels. A certified phlebotomist drew 8ml of blood in Corvac red top tubes (Mansfield, Massachusetts). The serum was separated by centrifuging the sample for ten minutes at 3,000RPM. Blood was stored at -18 Celsius until time of analysis. The serum vitamin D (25(OH)D) analysis was performed by Heartland Assays (Ames, Iowa) using the DiaSorin Liason platform. The Liason is an automated system that takes approximately 40 minutes. It has a sensitivity of less than 10 nmol/L, a 4% intraassay, and 6% interassay.[41] There is a 0.95 correlation coefficient when compared to the leading vitamin D (25(OH)D) analysis system, liquid chromatography-tandem mass spectrometry.[41]

Bench Press 1 Repetition Maximum

Muscular strength was assessed by testing the subject's estimated 1RM of the bench press. The subject was given warm-up sets of 10 repetitions using approximately 50-70% of their estimated 1 RM. Subjects then estimated their 1RM and that weight was placed on the bar. The subject was instructed to lay supine on the bench, have their feet on the ground approximately shoulder width apart, have their shoulders and back touching the bench, and to place their hands about shoulder width apart on the bar. The researcher provided supervision and spotting. The subject performed multiple repetitions until they can no longer perform any more lifts. The subjects 1 RM was determined using a multiple 1 RM conversion chart (Appendix E). If the subject completed more than 10 repetitions of the weight they were given a 2-4 minute break before the weight was increased and they performed the lift again until fatigue. All procedures for the estimated 1 RM followed the guidelines established by NSCA.[40]

Vertical Jump Height

Vertical jump height was measured using a jump and reach method. The subject covered the fingertips of one hand with chalk. The subject was instructed to stand flat-footed, reach as high as they can, and touch the wall. This mark indicated their standing reach height. They were given instructions to squat and jump, but were not allowed to take any steps. The subject was asked to jump and touch as high as they can. This mark is their jumping height. The vertical jump height was the difference measured with a standard tape measure between the standing height and the jumping height. The best of 3 attempts was recorded. The procedure for assessing vertical jump height has been proven a valid measure and followed the standards established by NSCA.[39,40]

40-Meter Sprint

The subject were instructed to run for 40 meters as fast as they could. The time was measured using the Bower electronic timing system (Draper, Utah), that started when the subject crossed the starting line and stopped when they cross the finish line. Only one attempt was performed.

Supplementation Protocol

Subjects were randomly assigned to the vitamin D treatment group or the placebo group by drawing a number out of an envelope. The vitamin D supplementation group took 50,000 IU of vitamin D_3, purchased from Biotech Pharmacal Inc. (Fayetteville, Arkansas), one time per week for eight weeks. The placebo group took one methylcellulose supplement, purchased from Letco Medical (Decatur, Alabama), one time per week for eight weeks. The methylcellulose was placed in capsules that were similar in size, shape, and color to the vitamin D supplements. The subjects were instructed not to change their dietary habits and workout during the eight week treatment period.

Statistical Analysis

Data analysis was performed using the Statistical Package for Social Sciences (v.22, SPSS, Inc., Chicago, IL). Central tendency score were used to measure central tendency scores. All experimental data was analyzed using a one-way ANOVA to determine differences between pre-test and post-test data of both the control and treatment group. The alpha level was set at $p<0.05$ for all analysis.

CHAPTER IV
MANUSCRIPT

Introduction

Many factors effect athletic performance including training, genetics, nutrition, and the environment. A combination of these factors can also influence the levels of serum vitamin D (25(OH)D) available for use in the body. Vitamin D is a fat-soluble, prohormone that is primarily obtained from ultraviolet radiation, but can also be gained from a small number of food sources.[2,7] In the last twenty years, there has been increasing evidence to show the numerous roles vitamin D plays throughout the body.[7] While vitamin D plays an important role in disease prevention and muscle function, a high incidence of vitamin D deficiency is reported. In the general population over 60% of children and 75% of adults are found to be vitamin D defieicnt.[1,43] Recent research has focused on vitamin D deficiency and supplementation in elderly and young populations.[10-17] Low levels of vitamin D are connected to many health related issues including low bone density, cancer, heart disease, and increased risk for infection.[41] In addition to these health related issues, vitamin D is the main binding site for the hormone, calcitriol, whose main function is to regulate the levels of calcium and phosphorus in the body. Calcium regulation is important because of its supporting role in muscle contraction and nerve conduction.[2,8] Vitamin D is also important because of its role in skeletal muscle tissue regulation through the vitamin D receptor (VDR).[7] The interaction between vitamin D and the VDR allows for mRNA transcription, protein synthesis, increased calcium uptake, and differentiation of cells into muscle tissue. [7,42] The functions of vitamin D in the muscle tissue indicate low vitamin D levels would lead to decreased muscle function. The discovery of muscle weakness, generalized pain, and poor muscle tone in children led to research on the supplementation of vitamin D to reverse these abnormalities.[9] Further investigations have examined the effects of supplementation on reaction time, balance, and neuromuscular function in older adults, and have found significant improvements in these measurements.[10-17]

While extensive research has investigated the effects of vitamin D on neuromuscular function in older adults, there is limited research on supplementation of vitamin D to help improve physical performance in athletes.[10-17] Recent studies have established that many athletes are vitamin D deficient, including many dancers and gymnasts.[1,18,19] In Europe, research has determined many professional or elite athletes across a variety of sports, are vitamin D deficient.[2,20-23] In the United States, the prevalence of vitamin D deficiency was examined in over 200 collegiate athletes and found nearly 70% did not meet adequate levels.[24] This research shows the increased prevalence of vitamin D deficiency is not only present in an elderly and young population, but also in athletic populations.[1,2,18-24]

To date, little evidence is available on the effects of supplementation on athletes or physically active individuals to determine if vitamin D can improve physical performance, muscle function, and return athletes to a normal serum vitamin D levels. Supplemented athletes with varying levels of vitamin D for varying lengths of time found serum vitamin D levels improved.[5,19,24,25] The research on prescribed dose of vitamin D and duration of supplementation improvements in physical performance is unclear. One investigation on ballet dancers found isometric strength and vertical jump were improved with vitamin D supplementation.[19] However, two other studies found no improvement in physical performance for athletes who were supplemented with vitamin D.[25,26] These inconsistencies show the lack of evidence to determine if vitamin D supplementation is an effective treatment to improve physical performance in a physically active population. Therefore, the purpose of this investigation is to determine if an eight-week supplementation of 50,000 IU of vitamin D_3 will reverse deficiency in a young, physically active population. A secondary purpose of this investigation is to determine if vitamin D_3 supplementation will increase a physically active person's musculoskeletal performance ability in a 40-meter sprint, one RM bench press, and vertical jump.

Methods

Design

This investigation was a double-blinded, randomized controlled trial made up of two treatment groups, vitamin D_3 (n=14) and control (n=15). The participant's serum 25(OH)D levels, 40-meter sprint, vertical jump height, and one repetition max (1RM) bench press were measured pre-supplementation then again after eight weeks of supplementation.

Participants

Twenty-nine physically active collegiate men (n=11) and women (n=18) (age =23.21± 1.52 yrs, weight =70.66±14.23 kg, height=171.18±9.03 cm) volunteered to participate in the investigation. All subjects included in the investigation were physically active for at least six months prior to the investigation and currently taking part in moderate intensity exercise for 30 minutes, five days per week or vigorous activity for 20 minutes, three days per week. Permission to conduct the investigation was granted by Texas State University Institutional Review Board. Each subject completed an informed consent, demographic sheet and medical history questionnaire before participating in the investigation. Exclusion from the investigation occurred if they subjects had a history of musculoskeletal injury, cardiovascular problems, history of diabetes, thyroid dysfunction, or excessive weight loss, which compromise the completion of the investigation protocol. Additionally, exclusion occurred if the subjects were currently taking fish oil, a multi-vitamin or vitamin D supplement. Subjects were randomly assigned to one of two groups by drawing a number out of an envelope.

Procedures

Subjects who met inclusion criteria contacted the investigator, signed up for a time to take part in the investigation, and provided contact information. On day one of the investigation the subject arrived at the testing site where they were informed of the procedures and expectations of the investigation. Subjects completed an informed consent page agreeing to take part in the investigation, a demographic information sheet, a medical history questionnaire, and a vitamin D consumption questionnaire adopted from Halliday et al.[3] Following completion of the paperwork, venous blood samples to assess vitamin D serum levels were collected from the cubital vein. After completing the initial blood testing, subjects were notified to return for pre-testing of performance measures and to begin supplementation. The treatment group received 50,000 IU of vitamin D_3, distributed by the principal investigator, one time per week for eight weeks. The placebo group received methylcellulose distributed by the principal investigator. Subjects were asked to report to the laboratory wearing exercise clothing and a short-sleeved shirt that exposed their cubital vein for blood testing. In addition, subjects were asked to refrain from having caffeine on the days of performance testing. Subjects performed a five-minute warm up and were allowed to perform five minutes of stretching of their choice. Baseline measurements were collected for physical performance measures. There was randomization of testing for each subject, and the subjects received five minutes of rest between each activity. After all testing was completed subjects returned to the research lab to receive the first week's supplement.

During weeks two through eight of the investigation the subjects met with the investigator to receive the supplements for the week. The day after taking their final supplement subjects returned for post-test measures following the same procedures as pre-test physical performance testing. Following performance testing, venous blood samples were collected. Vitamin D serum levels were collected within a two-hour time frame from the pre-test.

Vitamin D Assessment

Non-fasting venous blood samples were taken from the cubital vein. A certified phlebotomist drew 8ml of blood in Corvac red top tubes (Mansfield, MA). Centrifuging the sample for ten minutes at 3,000RPM separated the serum, and the serum was then stored at -18° Celsius until time of analysis. The serum vitamin D (25(OH)D) analysis was performed by Heartland Assays (Ames, Iowa) using the DiaSorin Liason platform.

Bench Press 1 Repetition Maximum

Testing the subject's estimated 1RM of the bench press assessed muscular strength. The subject performed warm-up sets using approximately 50-70% of their estimated 1 RM. Subjects estimated their 1RM and that weight was placed on the bar. The subject was instructed to lay supine on the bench, have their feet on the ground approximately shoulder width apart, have their shoulders and back touching the bench, and to place their hands about shoulder width apart on the bar. The researcher provided supervision and spotting. The subject performed multiple repetitions until they could no longer perform any more lifts. The subject's 1RM was then determined using a multiple 1 RM conversion chart established by the National Strength and Conditioning Association (NSCA).[40] If the subject completed more than 10 repetitions of the weight they were given a two to four minute break before the weight was increased and they performed the lift again until fatigue.

Vertical Jump Height

Vertical jump height was measured using a jump and reach method. The subject was instructed to rub chalk on the tips of the fingers of one hand. The subject was instructed to stand flat-footed and reach as high as they could for baseline measurement. The subject then jumped and touched the wall as high as they could measuring the distance between the top point of the standing touch and the jumping touch was measured. Subjects were given a 30 second rest between each jump, and the best of three attempts was recorded. The procedure for assessing vertical jump height followed the standards established by NSCA.[40]

40-Meter Sprint

The subject was instructed to run maximally for 40 meters on an indoor track. The time was measured using the Bower electronic timing system (Bertec Corp, Draper, UT). The timing system started when the subject crosses the starting line and stopped when they cross the finish line. Only one attempt was performed.

Supplementation Protocol

Subjects were randomly assigned to the vitamin D treatment group or the placebo group by drawing a number out of an envelope. The vitamin D supplementation group took 50,000 IU of vitamin D_3 (BioTech Pharmacal Inc. Fayetteville, AR) once a week for eight weeks. The placebo group took one methylcellulose supplement (Letco Med., Decatur, AL) per week. All supplement and placebo capsules were similar in size, shape, and color. The subjects were instructed to not change their dietary habits and workouts during the eight-week treatment period.

Statistical Analysis

Data analysis was performed using the Statistical Package for Social Sciences (v.21, SPSS, Inc., Chicago, IL). Central tendency score were used to measure central tendency scores. All experimental data were analyzed using a one-way ANOVA to determine differences between pre-test and post-test data of both the control and treatment group. The alpha level was set at $p<0.05$ for all analysis.

Results

Total serum 25(OH)D concentration significantly increased in the vitamin D supplementation group after eight weeks of supplementation with 50,000 IU of vitamin D (p=0.00). Prior to supplementation 19 of the 29 total subjects (66%) had vitamin D concentrations considered to be deficient (< 32 ng/ml). The mean serum 25(OH)D level prior to supplementation was 30.1 ± 7.7

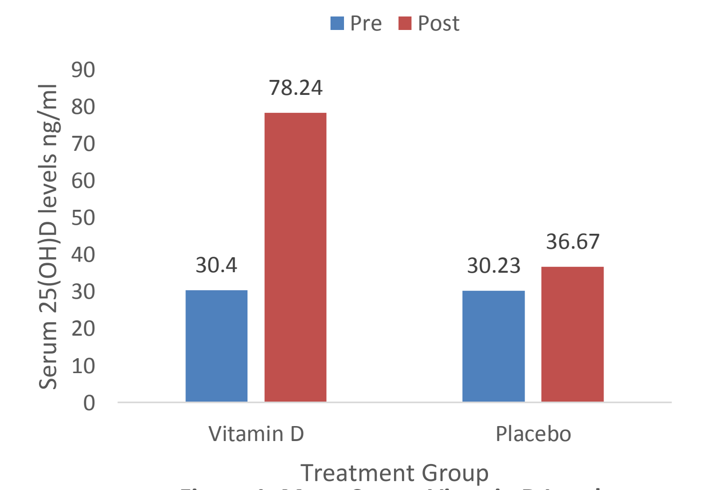

Figure 1. Mean Serum Vitamin D Levels

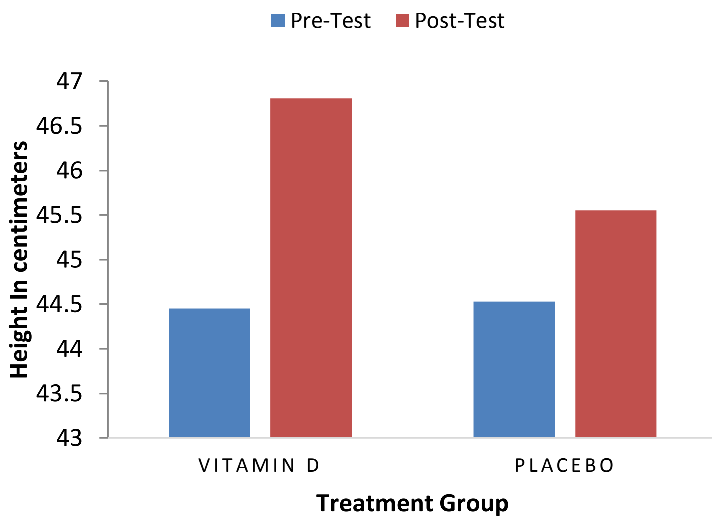

Figure 2. Mean Vertical Jump Height

ng/ml. After supplementation seven out of twenty-nine total subjects were vitamin D deficient. In the treatment group the mean serum 25(OH)D level prior to treatment was 30.4 ng/ml. Of the subjects receiving vitamin D supplementation 93% were below optimal levels of 50 ng/ml and 64% were vitamin D deficient. After eight weeks of 50,000 IU of vitamin D, 100% of the participants had reached optimal levels and the mean vitamin D serum concentration was 78.24 ng/ml. In the control group 10/15 (66%) of the subjects were vitamin D deficient pre-supplementation, and after eight weeks of placebo treatment 47% of the subjects were vitamin D deficient.

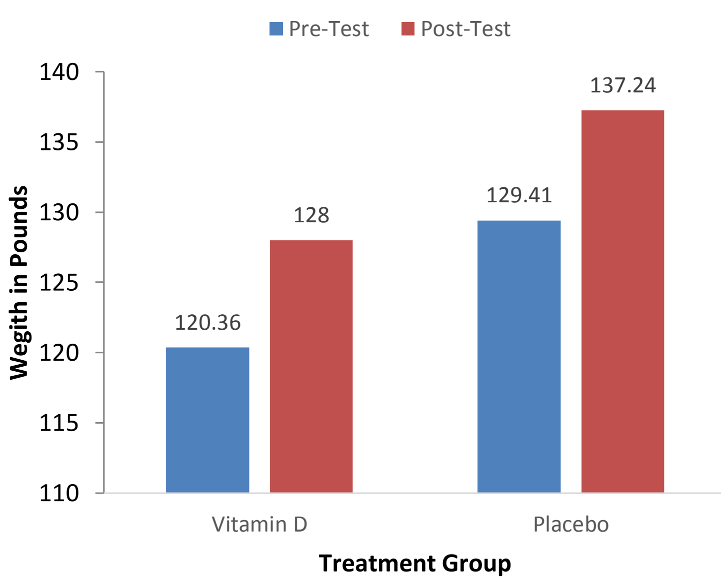

Figure 3. Mean 1RM Bench Press

Results from the performance tests are shown in Figure 2, 3, and 4. There were no significant differences found between the two groups in any of the performance tests measures over the eight week supplementation period (1RM bench press, p=0.583 ; vertical jump height, p=0.820; 40-meter sprint, p=0.969). In the treatment group there was a 6.4 % increase in bench press, a 5.3% increase in vertical jump height, and a 2.9% decrease in sprint time. While in the control group there was a 5.8% increase in bench press, a 2.3% increase in vertical jump height, and 3.8% decrease in sprint time.

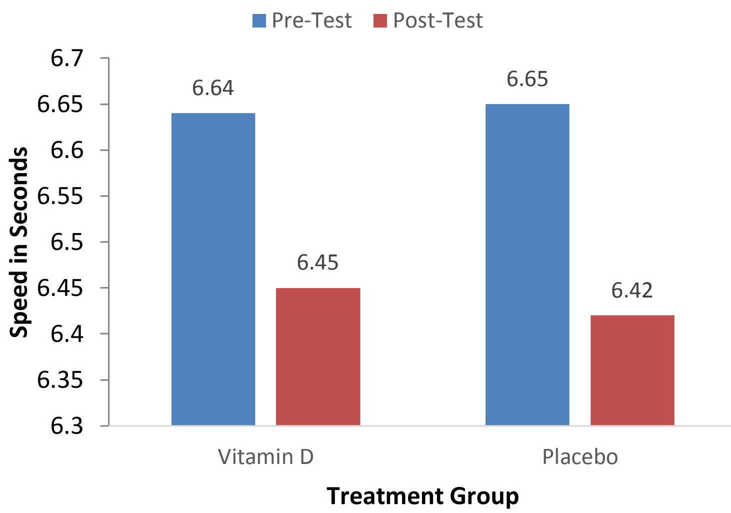

Figure 4. Mean 40-Meter Sprint

Discussion

The aim of this investigation was to examine the effects of 50,000 IU of vitamin D_3 on increasing vitamin D serum levels and physical performance measures in young, physically active adults. We found 50,000 IU of vitamin D for eight weeks was able to bring all subjects to optimal vitamin D serum 25(OH)D levels (50 ng/ml). However, in this study vitamin D supplementation had no effect on significantly increasing the physical performance measures of vertical jump height, 40-meter sprint, and 1RM bench press.

An extensive amount of research has established vitamin D deficiency is common in both the general and athletic populations.[9,13,20-24,32,33] In our investigation we found 66% of the physically active subjects were vitamin D deficient (<32 ng/ml) and 86% were below the optimal level (50ng/ml) further supporting the high incidence of vitamin D deficiency. This finding is comparable to other studies who have looked at vitamin D serum levels in college age (18-30 years) adults.[3,43] In a group of runners 42% had vitamin D serum levels below 32ng/ml.[31] Outside of the United States similar results have been found in club level athletes, 57% of subjects were vitamin D deficient at baseline.[26] In an investigation conducted by Close et al., 62% of the athletes and 73% of the controls were vitamin D deficient.[2] While the percentage of subjects who were vitamin D deficient were comparable in most studies, there were two studies who had a much larger percentage of deficient subjects.[18,44] One hundred percent of college aged Asian women and 100% of elite ballet dancers were found to be vitamin D deficient.[18,44] These large percentages of deficiency may be accounted for through indoor participation in ballet and ethnicity of the Asian women.

While the percentage of subjects who were vitamin D deficient was comparable to other studies the overall mean serum 25(OH)D level was higher in our investigation than others. The reported mean vitamin D serum level at baseline in this investigation was 30.1 ± 7.7 ng/ml, while in healthy Asain females the mean vitamin D serum level was 9.3 ±3.37 ng/ml and in 215 Norwegian adults between the ages of 18-50, the mean serum level was 26 nmol/ L (10.4 ng/ml) .[44, 45] Another investigation involving both professional athletes and healthy adults reported a mean of 29 ±25 nmol/l (11.6ng/ml).[2]

Although most studies reported mean values smaller than values found in this investigation there were two studies whose mean was larger. Halliday et al. found a serum 25(OH)D mean value of 40.1 ± 14.9 ng/ml in college level athletes, while Division I college athletes reported a mean value of 41.9 ± 14.6 ng/ml.[3, 24] While both of these means are larger than those reported in both this investigation and others this difference may be accounted for by the times of year the blood samples were taken. Both investigations drew samples in the spring or summer months when athletes tend to spend more time outside in the sun increasing their UV vitamin D absorption.[3,24] The larger numbers reported from our investigation may also be accounted for under this same reasoning. The participants in this investigation lived in a warmer climate, reported increased time to sun exposure, and the serum samples were drawn in the spring months.

While sun exposure may account for a large portion of vitamin D deficiency, nutritional sources should not be unaccounted for. Many American diets lack food with large sources of vitamin D. Most dietary vitamin D is consumed through lard and other fatty fish, which are not a common part of most American diets.[9] However, many dairy and cereal products have been fortified with vitamin D to try and meet dietary needs.[9] It should be considered a concern the only fortified foods are dairy products leaving those who are lactose intolerant at an increased risk for vitamin D deficiency.

The need for vitamin D supplementation is becoming more evident as recent research has shown the growing number of people who are vitamin D deficient because of the lack of dietary sources and sun exposure. However, there is much concern the current standards of supplementation are not adequate.[46] Along with the recommended daily dosage of vitamin D being an area of debate, optimal 25(OH)D blood serum concentrations vary among different organizations and researchers. For example the US Institute of medicine recommends vitamin D levels are adequate when greater than 50 nmol/l (20 ng/ml), whereas the Endocrine Society states 30-100 ng/ml is sufficient. While the adequate levels vary it is generally accepted that toxicity occurs at serum levels greater than 150 ng/ml.[46]

The 50,000 IU of vitamin D supplemented for eight weeks in this investigation is higher than most other research to date in a physically active population. At the end of the eight-week supplementation period, no subjects were vitamin D deficient and all had reached optimal levels greater than 50ng/ml. Club level athletes were supplemented with either 20,000 IU or 40,000 IU one time per week for 12 weeks. At the end of the supplementation period all the subjects were no longer classified as deficient, but only all of the subjects supplemented with 40,000 IU reached optimal levels.[26] Another study supplemented professional athletes and healthy adults with 5,000 IU one time per day for eight weeks, but only 60% of the total subjects reached optimal levels.[2] Overall, the research indicates less supplementation may return subjects to levels that are no longer considered deficient, but higher levels, at least initially, may be needed to bring subjects to optimal levels. However, more research should be conducted to determine the adequate dosage and amount of time necessary to reach optimal levels and then maintain them over time.

Not only is research of dosage of vitamin D insufficient, but the effects of vitamin D on physical performance measures is controversial. In an elderly population, research has established vitamin D supplementation can improve neuromuscular function, increase muscle strength, and reduce the risk of falls.[10-17] Muscle biopsy's in older, vitamin D deficient adults have indicated a decreased number of type II muscle fibers.[29] These findings in an elderly population indicate vitamin D plays an important role in muscle function and athletic performance. Therefore, research has now begun to look at the effects of vitamin D supplementation on physical performance in athletes and healthy adults.

This investigation looked at the effects of vitamin D supplementation on young, physically active adults. No significant improvements were found in 40-meter sprint, vertical jump height, or 1 RM bench press after eight weeks of supplementation with 50,000 IU one time per week. These findings were consistent with an investigation conducted by Close et al.[26] who supplemented club-level athletes with either 20,000IU or 40,000 IU one time per week for 12 weeks. The studies who were able to find improvements in physical performance measures found improvements in isometric measures and shorter (10-meter) sprint distances.[2,19] The types of physical performance measures where significant differences were found may indicate vitamin D plays more of a role in one type of muscle fiber over another. In addition to vitamin D affecting one fiber type more than another athletes may need higher vitamin D concentrations in order to see the significant improvements in muscle function that elderly populations receive. Age plays an important role in muscle degeneration allowing for vitamin D to have more of an effect on an elderly population than it would in a healthy, young population.

Significant differences in physical performance investigated in this investigation may not have been found due to the limitations of the investigation. There was a limited number of subjects indicating future research should use a larger sample size to determine the effects of vitamin D supplementation on physical performance. It would also be necessary to have a more structured training and diet plan for the subjects to follow during the supplementation period in order to determine the changes are directly related to the vitamin D supplementation. Another limitation to this investigation is the lack of familiarization period to the performance measures used in this investigation. Most of the subjects had prior experience with all of the exercises used, but in order to further enhance this investigation participants should have a familiarization period.

CHAPTER V
CONCLUSIONS

The purpose of this investigation was to determine if 50,000 IU of vitamin D_3 would reverse vitamin D deficiency in a young, physically active population. The secondary purpose of this investigation was to determine the effects of vitamin D supplementation on physical performance measured by 40-meter sprint, vertical jump height, and 1RM bench press. We found eight weeks supplementation of 50,000 IU of vitamin D_3 was able to bring 100% of the subjects to optimal (50ng/ml) serum 25(OH)D serum levels. However, we were not able to find a significant difference in physical performance measures at the end of the eight weeks.

Limitations and Future Research

As with any investigation there were limitations to this study. The first major limitation was the low number of participants included in the study. Future research should increase the number of participants to further increase the statistical significance. A second limitation is the lack of controlled diet and exercise program of the participants. Without the initiation of a dietary and training protocol the research is limited in determining if the changes or lack of changes are due to the supplementation of vitamin D or the varying diets and exercise programs of the participants. The final area where future research can enhance the study of vitamin D supplementation is by determining the length of time necessary to return participants to adequate serum levels as well as determining amount of vitamin D_3 that should be supplemented.

Appendix A
CONSENT FORM
Department of Health and Human Performance
Texas State University- San Marcos, Texas

The Effects of 8-week Vitamin D Supplementation on Musculoskeletal Performance in a Physically Active Population
IRB #:2015W9745

The principal investigators of this study are Kelsie Markin (kdm121@txstate.edu or 937-869-0358) and Dr. Jack Ransone (ransone@txstate.edu or 512-245-8176) at Texas State University. If you have any questions of concerns regarding this research study, please contact us by the email or phone number provided.

Research Purpose

The primary purpose of this investigation is to determine if vitamin D supplementation will increase a physically active person's musculoskeletal performance ability in a 50-meter sprint, 1 repetition max bench press, and vertical jump. A secondary purpose of this study is to determine if an 8-week supplementation of 50,000 IU of vitamin D_3 will reverse deficiency in a young, physically active population. You have been asked to participate in this investigation because you meet the inclusion criteria below and to help us improve our understanding of the effects of vitamin D supplementation on physical performance.

Procedure

Subjects between the ages of 18-30 from Texas State University will be selected to participate in this investigation. In order to participate you must take part in moderate-intensity aerobic exercise for 30 minutes 5 days per week or 20 minutes of vigorous activity three days per week. You must be vitamin D deficient. You will be instructed to wear athletic clothing and a short sleeve shirt to allow exposure of the cubital vein. The blood draw procedures for this investigation will be performed in the Department of Clinical Laboratory Science. The physical performance measures and all other meetings will take part in Jowers gyms. The investigation will take 9 weeks with a total of 11 meetings. The first meeting will take approximately one hour. The second meeting will take between one to one and a half hours. The following meetings will occur once a week for 8 weeks and will take approximately 15 minutes. The last meeting on week 9 will take approximately 2 hours.

Subjects who met inclusion criteria contact the investigator, sign up for a time to take part in the investigation, and provide contact information.
Day 1: Determining vitamin D serum levels

7. Subject will arrive at the testing site where they will be informed of the procedures and expectations of the investigation. Testing on day 1 will take approximately an hour.
8. Subjects will complete the informed consent page agreeing to take part in the investigation.
9. Subjects will complete a demographic information sheet including information about their age, weight, height, and sex.
10. Subjects will complete a medical history questionnaire. The health questionnaire will determine diabetes, heart problems, musculoskeletal injuries, and thyroid dysfunction. It will take approximately 2 minutes to complete.
11. Subjects will complete a vitamin D consumption questionnaire. This questionnaire will assess the amount of vitamin D consumed, possible sources of vitamin D, sun exposure, and what supplements the participant may be taking. It will take approximately 5 minutes to complete.
12. Venous blood samples to assess vitamin D serum levels will be collected from the cubital vein in the arm.

Day 2: Pre-testing of physical performance measures

If subjects were found to be vitamin D deficient after completing the initial blood testing they will be notified to return for pre-testing of performance measures and to begin supplementation. Testing on day two will take between 1-1.5 hours.

5. Subjects will be randomly assigned to the treatment group or placebo group by drawing a number out of an envelope.
6. Subjects will perform a 5-minute warm up on a stationary bike and be allowed to perform 5 minutes of stretching of their choice.
7. Baseline measurements will be collected for physical performance measures. The subjects will receive 5 minutes of rest between each test.
    a. Vertical Jump height will be assessed with the jump and reach method using the Vertec
    b. Muscular strength will be assessed by testing estimated 1 RM on the bench press.
    c. 50-meter sprint time via Brower electronic timing system (Draper, Utah).
8. After all testing is completed subjects will return to the research lab where they will receive the first week worth of supplements and that week's dietary log.

Weeks 2-8

2. Each week on your designated day you will meet with investigator to receive the supplements for the next week, 3 day dietary log for the next week, and to return the previous week's dietary log. Weekly meetings to receive supplementation will take 15 minutes.

Week 9- Posttest measurements

5. The day after taking their final supplement you will return to the research laboratory for post-test measures. This testing session will last approximately 2 hours.

6. You will perform a 5-minute warm up on a stationary bike and be allowed to perform 5 minutes of stretching of your choice.
7. Baseline measurements will be collected for physical performance measures. There will be randomization of testing for each subject, and you will receive 5 minutes of rest between each activity.
    a. Vertical Jump height will be assessed with the jump and reach method using the Vertec
    b. Muscular strength will be assessed by testing estimated 1 RM on the bench press
    c. 50-meter sprint time via Brower electronic timing system (Draper, Utah).
8. Venous blood samples to assess vitamin D serum levels will be collected from the cubital vein. They will be collected during the same time of day (within 2 hours) of initial blood testing.

Possible Benefits

1. The subjects will determine if they are vitamin D deficient.
2. The subjects will see the possible benefits of vitamin D on physical performance.
3. The subjects will see the possible benefits of vitamin D supplementation on reversing deficiency.

Potential Risks

1. The subjects may experience minimal discomfort with blood draws. These discomforts may include bruising, soreness, and minimal pain from needle.
2. The subjects may experience muscle soreness from physical performance measures.
3. The subjects have an increased risk of an ankle sprain or muscle strain due to the sprinting and jumping activities they will be taking part in.

These inherent risks are not considered life threatening and will resolve within a week. The risks will be minimized to the best of the principle investigators ability. Kelsie Markin, a Certified Athletic Trainer, will be monitoring all aspects of research. In the event of an emergency, emergency personnel (911) will be contacted. If calling 911 is not warranted the participant will be directed to treatment at one of the following locations. Payment of any injury or cost resulting from this study will be the responsibility of the individual.

1. Student Health Center. 298 University Drive San Marcos, TX 78666. (512) 245-2161
2. Central Texas Medical Center. 1301 Wonder World Drive San Marcos, TX 78666. (512) 353-8979
3. Seton Medical Center. 6001 Kyle Parkway Kyle, TX 78640. (512) 504-5000

Confidentiality

The data collected during this study will be kept confidential by issuing each subject a subject number that will be stored in a master list. This number will be used for collecting and tracking the subjects throughout the investigation. All the data will be kept in the locked office in a locked cabinet of the principal investigator. Access to the files is only for the principal investigators Kelsie Markin and Dr. Jack Ransone. Other individuals who will have access to this data include committee members Dr. Joni Mettler and Jeff Housman. All data with personal information will be destroyed after the study is complete.

Results

If requested, subjects may receive a summary of the results of the study upon completion. To receive results please contact the principal investigator Kelsie Markin by phone or email.

Participation

Your participation in this study is voluntary and you will not be penalized if you choose not to participate. You are free to withdraw from the study at any point during the investigation without penalty. If you withdraw from the study, the information sheets and data will be destroyed. Subjects may choose not to answer any questions for any reason without penalty. This project, IRB # 2015W9745, was approved by the Texas State IRB on (insert date). Pertinent Questions regarding participations rights and/or questions about research related injuries can be answered by contacting the IRB chair, Dr. Jon Lasser (512-245-3413 or lasser@txstate.edu) or Becky Northcut, Director, Research Integrity & Compliance (512-245-0210 of bnorthcut@txstate.edu).

Subject Name ________________________________

Subject Signature ____________________________________ Date _________

Investigator Signature _________________________________ Date________________

Appendix B
Subject Information Sheet

Date:______________ **Subject ID number:**___________________

Group Assignment: Group 1 / Group 2 **Gender:** Male / Female

Age:______________ **Height:**_____________ **Weight:**____________

Pre-Test Measurements:

Muscular Strength: Bench Press	
Selected Weight	
Number of Lifts	
Estimated 1 RM	

40 Meter Sprint	
Time (Sec)	

Vertical Jump Height			
1st	2nd	3rd	Best Attempt

Blood Testing	
Vitamin D Serum Levels	

Post Test Measurements:

Muscular Strength: Bench Press	
Selected Weight	
Number of Lifts	
Estimated 1 RM	

40 Meter Sprint	
Time (Sec)	

Vertical Jump Height			
1st	2nd	3rd	Best Attempt

Blood Testing	
Vitamin D Serum Levels	

Appendix C
Medical History Questionnaire

Please answer the questions below by checking yes or no.

Activity Level	**Yes**	**No**
Are you physically active? (Do you work out at least 3 days a week for 30 minutes?)		
Have you been physically active for at least the past 6 months?		
Medical History	**Yes**	**No**
1. Do you experience chest discomfort with exertion?		
2. Do you experience unreasonable breathlessness with exertion?		
3. Do you have a history of heart problems?		
4. Do you experience rapid or forced heartbeats?		
5. Have you ever experienced lightheadedness, fainting, or blackouts?		
6. Have you ever been told by a physician not to work out?		
7. Do you have any knee, ankle, or foot injuries that prevent you from working out?		
8. Do you have any arm injuries that prevent you from lifting weights or working out?		
9. Are you diabetic?		
10. Have you been diagnosed with a thyroid disorder?		
11. Have you lost weight in the last 3 month? If so how much?		

If you answered yes to any of the question above please explain.

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Appendix D
Vitamin D Questionnaire

Foods Section

For each food listed, check the box indicating how often on average you have used the amount specified during the last three months (since you last completed this questionnaire).

Foods Consumed	**Never or < 1 per mo.**	**1-3 per month**	**1 per week**	**2-4 per week**	**5-6 per week**	**1 per day**	**2-3 per day**	**4-5 per day**	**6+ per day**
1. Milk, Vitamin D fortified, 1 cup									
2. Soy Milk or Rice Milk, Vitamin D fortified, 1 cup									
3. Cereal, Vitamin D fortified (Total Corn Flakes,									
Kellogg's Raisin Bran, Oat Bran, Cheerios), ¾ Cup									
4. Margarine, Vitamin D fortified (Promise, etc.), 1 teaspoon									
5. Orange Juice, Vitamin D fortified (Tropicana, Florida's Natural), 1 cup									
6. Liver, cooked, 3 ½ oz.									
7. Egg, 1 whole									
8. Cod liver oil, 1 tablespoon									
9. Salmon, cooked, 3 ½ oz.									
10. Mackerel, cooked, 3 ½ oz.									
11. Sardines, canned in oil, 3 ½ oz.									
12. Eel, cooked, 3 ½ oz.									
13. Other Fatty Fish, 3 1/2 oz.									
14. Other Vitamin D fortified food, if applicable.									

Supplements Section
For each supplement, check the box indicating how often on average you have used the amount specified during the last three months (since you last completed this questionnaire).

Supplements Consumer	**< 1 per mo.**	**mont h**	**wee k**	**wee k**	**wee k**	**da y**	**da y**	**da y**	**da y**
1. Multiple Vitamin, 1 Tablet									
2. Calcium Vitamin, 1 Tablet									
3. Calcium + Vitamin D (Viactiv), 1 Tablet									

If you take any of the above three, please list, which you use, brand name, etc.

Sunlight Section
For each, check the amount used in each situation during the last three months (since you last completed this questionnaire).

	Never or < 1 hour per mo.	**1- 3 hr. per mo.**	**1 hr. per wk.**	**2-4 hr. per wk.**	**5-6 hr. per wk.**	**1/2 -1 hr. per day**	**> 2 hrs. per day**
1. How much leisure time is spent outside in the sun?							
	Never or <10 min per wk.	**10-20 min per wk.**	**20-30 min per wk.**	**30-40 min per wk.**	**40-50 min per wk.**	**50-60min per wk.**	**>60 min per wk.**
2. How often do you use tanning beds?							

`

For each, circle the amount used in each situation during the last three months (since you last completed this questionnaire).

3. How often do you use sunscreen?
   Never Sometimes Usually Always
   What SPF of sunscreen do you use? ___________________

4. How many minutes are spent each day walking to and from class?
   15 min. 30 min 45 min 1 hour > 1 hour

5. Where were you living in the last three months? City: State:

6. If applicable, where did you spend Winter Break? City: State:

7. If applicable, where did you spend Spring Break? City: State:

8. What is your Race/Ethnicity? ________________________________

9. When you are outside (in the last few months) do you typically wear: (Circle all that apply)

Long sleeves Short sleeves Shorts No shirt Sports bra

Baseball Hat Hat (other) Pants Gloves

Appendix E
Conversion Chart
Table 26.1 Estimating One-Repetition Maximum

% of 1 RM:	100.0	93.5	91.0	88.5	86.0	83.8	81.0	78.5	76.0	73.5
Repetitions	1	2	3	4	5	6	7	8	9	10
Weight lifted (lb):	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	5.0	4.7	4.5	4.4	4.3	4.2	4.1	3.9	3.8	3.7
	10.0	9.4	9.1	8.9	8.6	8.4	8.2	7.9	7.6	7.4
	15.0	14.0	13.7	13.3	12.9	12.5	12.2	11.8	11.4	11.0
	20.0	18.7	18.2	17.7	17.2	16.7	16.2	15.7	15.2	14.7
	25.0	23.4	22.8	22.1	21.5	20.9	20.2	19.6	19.0	18.4
	30.0	28.1	27.3	26.6	25.8	25.1	24.3	23.6	22.8	22.1
	35.0	32.7	31.9	31.0	30.1	29.2	28.4	27.5	26.6	25.7
	40.0	37.4	36.4	35.4	34.4	33.4	32.4	31.4	30.4	29.4
	45.0	42.1	41.0	39.8	38.7	3706	36.5	35.3	34.2	33.1
	50.0	46.8	45.4	44.3	43.0	41.8	40.5	39.3	38.0	36.8
	55.0	51.4	50.1	48.7	47.3	45.9	44.6	43.2	41.8	40.4
	60.0	56.1	54.6	53.1	51.6	50.1	48.6	47.1	45.6	44.1
	65.0	60.8	59.2	57.5	55.9	54.3	52.7	51.0	49.4	47.8
	70.0	65.5	63.7	62.0	60.2	58.5	56.7	55.0	53.2	51.5
	75.0	70.1	683.	66.4	64.5	62.6	60.8	58.9	57.0	55.1
	80.0	74.8	72.8	70.8	68.8	66.8	64.8	62.8	60.8	58.8
	85.0	79.5	77.4	75.2	73.1	71.0	68.9	66.7	64.6	62.5
	90.0	84.2	81.9	79.7	77.4	75.2	72.9	70.7	68.4	66.2
	95.0	88.8	86.5	84.1	81.7	79.3	77.0	74.6	72.2	69.8
	100.0	93.5	91.0	88.5	86.0	83.5	81.0	78.5	76.0	73.5
	105.0	98.2	95.6	92.9	90.3	87.7	85.1	82.4	79.8	77.2
	110.0	102.9	100.1	97.4	94.6	91.9	89.1	86.4	83.6	80.9
	115.0	107.5	104.7	101.8	98.9	96.0	93.2	90.3	87.4	84.5
	120.0	112.2	109.2	106.2	103.2	100.2	97.2	94.2	91.2	88.2
	125.0	116.9	113.8	110.6	107.5	104.4	101.3	98.1	95.0	91.9
	130.0	121.6	118.3	115.1	111.8	108.6	105.3	102.1	98.8	95.6
	135.0	126.2	122.9	119.5	116.1	112.7	109.4	105.0	102.6	99.2
	140.0	130.9	127.4	123.9	120.4	116.9	113.4	109.9	106.4	102.9
	145.0	135.6	132.1	128.3	127.7	121.1	117.5	113.8	110.2	106.6
	150.0	140.3	136.5	132.8	129.0	125.3	121.5	117.8	114.0	110.3
	155.0	144.9	141.1	137.2	133.3	129.4	125.6	121.7	117.8	113.9
	160.0	149.6	145.6	141.6	137.6	133.6	129.6	125.6	121.6	117.6
	165.0	154.3	150.2	146.0	141.9	137.8	133.7	129.5	125.4	121.3
	170.0	159.0	154.7	150.5	146.2	142.0	137.7	133.5	129.2	125.0
	175.0	163.6	159.3	154.9	150.5	146.1	141.8	137.4	133.0	128.6
	180.0	168.3	163.8	159.3	154.8	150.3	145.8	141.8	137.4	132.3
	185.0	173.0	168.4	163.7	159.1	154.5	149.9	145.2	140.6	136.0
	190.0	171.7	172.9	168.2	163.4	158.7	153.9	149.2	144.4	139.7
	195.0	182.3	177.5	172.6	167.7	162.8	158.0	153.1	148.2	143.3

(continued)

% of 1 RM:	100.0	93.5	91.0	88.5	86.0	83.8	81.0	78.5	76.0	73.5
Repetitions	1	2	3	4	5	6	7	8	9	10
Weight lifted (lb):	200.0	187.0	182.0	177.0	172.0	167.0	162.0	157.0	152.0	147.0
	205.0	191.7	186.6	181.4	176.3	171.2	166.1	160.9	155.8	150.7
	210.0	196.4	191.1	185.9	180.6	175.4	170.1	164.9	159.6	154.4
	215.0	201.0	195.7	190.3	184.9	179.5	174.2	168.8	163.4	158.0
	220.0	205.7	200.2	194.7	189.2	183.7	178.2	182.7	167.2	161.7
	225.0	210.4	204.8	199.1	193.5	187.9	182.3	176.6	171.0	165.4
	230.0	215.1	209.3	203.6	197.8	192.1	186.3	180.6	174.8	169.1
	235.0	219.7	213.9	208.0	202.1	196.2	190.4	184.5	178.6	172.7
	240.0	224.4	218.4	212.4	206.4	200.4	194.4	188.4	182.4	176.4
	245.0	229.1	223.0	216.8	210.7	204.6	198.5	192.3	186.2	180.1
	250.0	233.8	227.5	221.3	215.0	208.8	202.5	196.3	190.0	183.8
	255.0	238.4	232.1	225.7	219.3	212.9	206.6	200.2	193.8	187.4
	260.0	243.1	236.6	230.1	223.6	217.1	210.6	204.1	197.6	191.2
	265.0	247.8	241.2	234.5	227.9	221.3	214.7	208.1	201.4	194.8
	270.0	252.5	245.7	239.0	232.2	225.5	218.7	212.0	205.2	198.5
	275.0	257.1	250.3	243.4	236.5	229.6	222.8	215.9	209.0	202.1
	280.0	261.8	254.8	247.8	240.8	233.8	226.8	219.8	212.8	205.8
	285.0	266.5	259.4	252.2	245.1	238.0	230.9	223.7	216.6	209.4
	290.0	271.2	263.9	256.7	249.4	242.5	234.9	227.7	220.4	213.2
	295.0	275.9	268.5	261.1	253.7	246.3	239.0	231.6	224.2	216.8
	300.0	280.5	273.0	264.4	258.0	250.5	243.0	235.5	228.0	220.5
	305.0	285.2	277.6	269.9	262.3	254.7	247.1	239.4	231.8	224.2
	310.0	289.9	282.1	274.4	266.6	258.9	251.1	243.4	235.6	227.9
	315.0	294.5	286.7	278.8	270.9	263.0	255.2	247.3	239.4	231.5
	320.0	299.2	291.2	283.2	275.2	267.2	259.2	251.2	243.2	235.2
	325.0	303.9	295.8	287.6	279.5	271.4	263.3	255.1	247.0	238.9
	330.0	308.6	300.3	292.1	283.8	275.9	267.3	259.1	250.8	242.6
	335.0	313.2	304.9	296.5	288.1	279.7	271.4	263.0	254.6	246.2
	340.0	317.9	309.4	300.9	292.4	283.9	275.4	266.9	258.4	249.9
	345.0	322.6	314.0	305.3	296.7	288.1	279.5	270.8	262.2	253.6
	350.0	327.3	318.5	309.8	301.0	292.3	283.6	274.8	266.0	257.3
	355.0	331.9	323.1	314.2	305.3	296.4	287.6	278.7	269.8	260.9
	360.0	336.6	327.6	318.6	309.6	300.6	291.6	282.6	273.6	264.6
	365.0	341.3	332.2	323.0	313.9	304.8	295.7	286.5	277.4	268.3
	370.0	346.0	336.7	327.5	318.2	309.0	299.37	290.5	281.2	272.0
	375.0	350.6	341.3	331.9	322.5	313.1	303.8	294.4	285.0	275.6
	380.0	355.3	345.8	336.3	326.8	317.3	307.8	298.3	288.8	279.3
	385.0	360.0	350.4	340.7	331.1	321.5	311.9	302.2	292.6	283.0
	390.0	364.7	354.9	345.2	335.4	325.7	315.9	306.2	296.4	286.7
	395.0	369.3	359.5	349.6	339.7	329.8	320.0	310.1	300.2	290.3

* Adapted from: Baechle TR, Earle RW. Essentials of Strength Training and Conditioning/National Strength and Conditioning Association. Third Edition. Champaign, IL: Human Kinetics; 2008

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