EFFECTIVENESS OF BAPS TRAINING ON BALANCE

by

Tiffany D. Dziuk B.S.

A thesis submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Master of Science
with a Major in Exercise Science
August 2019

Committee Members:

Duane V. Knudson, Chair

Stacy D. Hunter

Andrea L. Green

FAIR USE AND AUTHOR'S PERMISSION STATEMENT

Fair Use

This work is protected by the Copyright Laws of the United States (Public Law 94-553, section 107). Consistent with fair use as defined in the Copyright Laws, brief quotations from this material are allowed with proper acknowledgement. Use of this material for financial gain without the author's express written permission is not allowed.

Duplication Permission

As the copyright holder of this work I, Tiffany D. Dziuk, refuse permission to copy in excess of the "Fair Use" exemption without my written permission.

DEDICATION

I would like to dedicate this thesis to my loving family. If it were not for their constant support in life I would not be the person or student that I am today. My mother and father have blessed me so much in this lifetime that words will never be able to justify how grateful I am for their love. I would also like to thank my little sister for being very supportive and always comforting me in times of stress and crisis. With your love and support I was able to complete my master's degree thesis. Thank you so much.

ACKNOWLEDGEMENTS

I would like to thank all of my professors at Texas State University, without their passion and support I would not be the student I am today. My board, Dr. Duane Knudson, Dr. Stacey Hunter, and Andrea Green, I would have been lost without you all. Thank you for taking time out of your busy schedules to assist me in this process. I would also like to thank Dr. Knudson specifically for supporting me though this entire journey and allowing me to learn from my mistakes. With your expert help I have grown as a student researcher and writer. I hope to take all the information you have taught me and apply it in my future career. Thank you so very much.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviation	Description
CAI	Chronic Ankle Instability
BESS	Balance Error Scoring System
SEBT	Star Excursion Balance Test
BAPS	Biomechanical Ankle Platform System
FAI	Functional Ankle Instability
ROM	Range of Motion
SD	Standard Deviation

1. ANKLE INJURIES AND REHABILITATION

Ankle Injury Occurrence and Recurrence

Ankle joint injuries are the second most common injured body site in sports, ankle sprains are the most common of these ankle joint injuries (Delahunt, et al., 2010). Ankle sprains are most common in sports that include jumping and running such as basketball, football, and volleyball (Payne, Berg, & Latin, 1997). However, these injuries are not specific to athletes, but to the general population (Bridgman, et al., 2003; Fong, Hong, Chan, Yun, & Chan, 2007). Lateral ankle injuries specifically are the most occurring lower extremity injury and account for as much as 10-15% of all injuries (Garrick, 1977; Kannus & Renstrom, 1991). Backx, Beijer, Bol, and Erich (1991), reported that 10% emergency room visits are related to ankle joint injuries and of those injuries approximately 75% are sprains. Lateral ankle sprains are responsible for 25% of all injury time loss from athletics (Manfroy, Ashton-Miller, & Wojtys, 1997). These common injuries may temporarily limit an individuals' ability to complete daily or sport related tasks.

A single ankle sprain may lead to balance impairments, recurrent instability, and recurrent sprains; these issues are commonly grouped together and termed chronic ankle instability (CAI) (Arnold, De La Motte, Linens, & Ross, 2009; McKeon & Mattacola, 2008). CAI is described as a sensation of "giving way" and functional deficits include poor balance, delayed muscle activation, decreased muscle strength, and impaired sensorimotor function (Linens, Ross, & Arnold, 2016). Functional ankle instability (FAI) is a term first presented by Freemann, Dean, and Hanham, (1965), also describing the sensation of giving way or feeling joint instability after repeated ankle sprains. FAI commonly involve sensorimotor, mechanical, and muscular deficiencies (Hertel, 2000; Kaminski, Buckley, Powers, Hubbard, & Ortiz, 2003; Konradsen & Magnusson, 2000). Acute medical treatment includes rest, cryotherapy, compression, and elevation. Despite these efforts and a variety of rehabilitation exercise programs patients' reinjure their ankle 20-74% of the time (Braun, 1999; Freeman et al., 1965; Smith & Reischl, 1986; Torg, 1982). Acute symptoms of ankle sprains resolve quickly but individuals still report pain and instability up to 7 years after initial injury (Van Rijn et al., 2003; Konradsen, Bech, Ehrenbjerg, & Nickelsen, 2002).

Several tests have been created to analyze CAI for clinical and research settings, these include Balance Error Scoring System (BESS), time-in-balance test, foot lift test, force-plate measures (center of pressure motion), and functional measures like the Star Excursion Balance Test [SEBT] (Arnold et al., 2009; Hertel, 2002; Linens, Ross, Arnold, Gayle, & Pidcoe, 2014). These tests are used to measure progress in participants' balance recovery using measures like velocity and width of center of pression movement on the base of support, as well as reach length of the lower extremity without losing balance. With training, participants decrease their velocity and width which leads to increases in their proprioceptive balance. Evidence has revealed that performing rehabilitation exercises improves qualities associated with balance and decreases residual symptoms (Bernier & Perrin, 1998; Gauffin, Tropp, & Odenrick, 1988; Linens et al., 2016; Matasusaka, Yokoyama, Tsurusaki, Inokuchi, & Okita, 2001; Tropp, Askling, & Guilquist, 1985; Verhagen et al., 2004; Wester, Jespersen, Nielsen, & Neumann, 1996).

Developing Rehabilitation Programs

As injured ligaments heal, physical therapists have developed ankle rehabilitation programs focusing on two influential factors of CAI, strength of ankle musculature and proprioception (Blackburn, Guskiewicz, Petschauer, & Prentice, 2000). These ankle rehabilitation programs assist in restoring ankle function by improving tissue size, flexibility, muscular strength, and endurance. Ankle rehabilitation commonly includes proprioceptive exercises which reduce the risk of joint re-injury (Osborne & Rizzio, 2003). These programs often include single leg stance, balance, coordination exercises, and ankle disk training (Zouita et al., 2013). Protocols often consist of as many as 12-18 exercises with a combination of different tools (Eils & Rosenbaum, 2001; Mattacola & Dwyer, 2002; Hale, Hertel, Olmsted-Kramer, 2007; Lee et al., 2012).

While there is not one particular rehabilitation technique proven best, research has reported there has been more consistent success with ankle disk training (Mattacola & Dwyer, 2002). Ankle disk training consists of various tools including wobble board, rocker board, or biomechanical ankle platform system (BAPS) boards; these tools are unstable surfaces that require the individual to perform motions that stress the ankle joint. Research using ankle disk training tools has suggested it increases postural awareness and decreases CAI symptoms (Osborne & Rizzio, 2003). Training on unstable surfaces can increase stable surface balance because the muscles of the lower kinetic chain are worked more vigorously, allowing for better stability on stable surfaces (Clark & Burden, 2005; Lee & Lin, 2008; Hoffman & Payne 1995). One of the most common proprioceptive rehabilitation tools for ankle injury is the BAPS board.

Biomechanical Ankle Platform System

Research conducted by Cain, Garceau, and Linens (2017) examined the effect of a 4-week BAPS training program on static and dynamic balance in high school athletes with chronic ankle instability. Twenty-two high school participants were divided into a rehabilitation (REH) or control group (CON). Participants completed an inclusion criteria questionnaire assessing activity level, residual symptoms (swelling, pain, or weakness), 2 or more moderate ankle sprains in the same ankle, and "giving way" symptoms. Exclusion criteria included previous surgery on the ankle joint, fracture, acute signs and symptoms or any balance disorders (Delahunt et al., 2010; Gribble et al., 2013). Upon collection of participants' height, weight, and leg length, baseline measurements were then evaluated using the time in balance test, foot lift test, SEBT, and side hop test in a counterbalanced manner.

After initial measurements were collected, the REH group began the rehabilitation protocol. Patients completed clockwise and counterclockwise rotations on the BAPS board near a wall (using fingertips for support) beginning on level 1 of 5. Participants selected their initial direction and alternated direction every 10 seconds. Five 40-second trials were completed with a 1-minute rest between each trial. Tukey post hoc analysis tested for significant interactions and displayed the REH group improved performance from pretest to posttest. REH experienced an increase in static balance by 50% for time in balance and dynamic balance increased by 25% for side hop. These increases were likely due to the dynamic aspects of the exercises which increased strength in key muscles and use of kinesthetic information from mechanoreceptors (Lee & Lin, 2008; Soderberg, Cook, Rider, & Stephenitch, 1991).

A 12-week BAPS study examined the relationship between single-leg postural stability and ankle reposition (Lee & Lin, 2008). The study observed 12 young participants (4 females and 8 males) with unilateral FAIs before and after the BAPS intervention. Following informed consent, participants completed limb dominance tests (ball kick, step-up, and balance recovery) which resulted in 7 FAI in dominant limbs and 5 FAIs in non-dominant limb. Participants completed a self-report questionnaire documenting injury history and were not currently involved in exercise training or rehabilitation programs prior to beginning the study.

To meet the criteria, participants must satisfy at least 1 of 5 FAI criteria established from previous research (Caulfield & Garrett, 2004; Kaminski et al., 2003). Single leg balance was analyzed by having participants stand barefoot flexing 90 degrees at the hip and knee with arms by their side atop a force platform with their eyes open. Participants mean center of pressure (COP) displacements were recorded assuming as values decrease, participants are experiencing increased postural control. Single leg balance tests were selected because of previously demonstrated moderate to excellent group reliability (Le Clair & Riach, 1996) and therefore are an acceptable exercise for comparing balance performance (Birmingham, 2000).

This study selected BAPS as the training device because of its popularity among athletic training and clinical rehabilitation settings. Participants began on the lowest level of the BAPS board completing 3 sets of 10 repetitions in anterior-posterior cycles, medial-lateral cycles, clockwise rotations, counterclockwise rotations, and single-leg stability (10 second trials). These exercises were completed 3 times a week for 12 weeks with minimal upper body use. At the completion of the study all subjects had reached level 3 and 8 participants had reached level 4. Results displayed that participants with FAI experienced a 16% increase in balance after completing a 12-week training program. This study further supports the use of BAPS as a rehabilitation tool for subjects with unilateral FAI. It demonstrates that BAPS training improves postural stability and ankle proprioception by improving neuromuscular ability and joint stability.

Rehab Duration

There are several studies that examine rehabilitation programs at different lengths, however, there is little research evaluating the most effective amount of time for an ankle rehabilitation program. Cain et al. (2017) conducted a 4-week BAPS research study and found that participants increased balance by 25-50%. 19 male participants with CAI were selected to complete a 4-week wobble board rehabilitation program (Clark & Burden, 2005). The CAI participants experienced a decrease in muscle onset latency at the completion of the study. Another 4-week rehabilitation study used destabilization devices to examine the effects of self-reported function, ROM, strength, and balance in patients with CAI (Donovan et al., 2016). This study reported participants self-reported function and ankle strength increased after 4-weeks of destabilization training.

Six-week rehabilitation programs are another common length for ankle rehabilitation. A 6-week wobble board training protocol was used to analyze the effect on posture and gait (Adedoyin, Olagun, Omotayo, Olawale, & Egwu, 2008). The experimental group experienced an increase in weight distribution symmetry by 9% after wobble board training. The relationship of time on a rehabilitation program was examined in a 6-week wobble board training program. Participants experienced isometric increases by 56-133% from pre-test data to post-test data (Balogun, Adesinasi, & Marzouk, 1992).

Gauffin, et al. (1988) observed the relationship between an 8-week ankle disk training and postural sway. Their research found that men with FAI had increased postural sway by 67% after the completion of the rehabilitation program. In a longer study, participants with unilateral FAI completed a 12-week BAPS program (Lee & Lin, 2008). At the completion of the 12 weeks, participants COP radius was significantly reduced by 28%. These research studies have all supported ankle rehabilitation programs as a successful strategy in increasing balance but have failed to determine which exercises are most beneficial and what period of time is best suited for ankle recovery.

HUMAC Balance Platform

The HUMAC balance system results consistently comparative small margin of displacement error under static conditions (Koltermann, Gerber, Beck, & Beck, 2017). Researchers have tested the COP function on the HUMAC because of its cost-effectiveness, portability, and relevance in day-to-day clinical practice. After calibration it revealed an acceptable maximum of .18% error with high reproductivity. The absolute error for the HUMAC was under 6.60 mm and was the lowest when compared to the Kistler plate.

Literature Cited

Adedoyin, R., Olaogun, M., Omotayo, K., Olawale, O. & Egwu, M. (2008). Effects of wobble board training on weight distribution on the lower extremities of sedentary subjects. *Technology and Health Care*, 16, 247-253.

Arnold, B., De La Motte, S., Linens, S., & Ross, S. (2009). Ankle instability is associated with balance impairments: a meta-analysis. *Medicine and Science in Sports and Exercise,* 41(5), 1048-1062. doi: 10.1249/MSS.0b013e318192d044

Backx, F., Beijer, H., Bol, E., & Erich, W. (1991). Injuries in high risk persons and high risk sports; A longitudinal study of 1818 school children. *The American Journal of Sports Medicine*, 19(2), 124-130.

Balogun, J.A., Adesinasi, C.O. & Marzouk, D.K. (1992). The effects of a wobble board exercise training program on static balance performance and strength of lower extremity muscles. *Physiotherapy Canada*, 23, 332-336.

Bernier, J., & Perrin, D. (1998). Effect of coordination training on proprioception of the functionally unstable ankle. *Journal of Orthopaedic Sports Physical Therapy*, 27, 264-275.

Birmingham, T. (2000). Test–retest reliability of lower extremity functional instability measures. *Clinical Journal of Sport Medicine*, 10(4), 264–268.

Blackburn, T., Guskiewicz, K., Petschauer, M. & Prentice, W. (2000). Balance and joint stability: the relative contributions of proprioception and muscular strength. *Journal of Sport Rehabilitation*, 9, 315-328.

Bridgman, S., Clement, D., Downing, A., Walley, G., Phair, I., & Maffulli, N. (2003). Population based epidemiology of ankle sprains attending accident and emergency units in the west midlands of England, and a survey of UK practice for severe ankle sprains. *Emergency Medical Journal*, 20(6), 508-510. 10.1136/emj.20.6.508

Braun, B. (1999). Effects of ankle sprain in a general clinic population 6 to 18 months after medical evaluation. *Archives of Family Medicine*, 1999, 8(2), 143– 148.

Cain, M. S., Garceau, S. W., & Linens, S. W. (2017). Effects of a 4-week biomechanical ankle platform system protocol on balance in high school athletes with chronic ankle instability. *Journal of Sport Rehabilitation*, 26(1), 1-7. doi: 10.1123/jsr.2015-0045

Caulfield, B., & Garrett, M. (2004). Changes in ground reaction force during jump landing in subjects with functional instability of the ankle joint. *Clinical Biomechanics*, 19, 617–621. doi:10.1016/j.clinbiomech.2004.03.001

Clark, V., & Burden, A. (2005). A 4-week wobble board exercise programme improved muscle onset latency and perceived stability in individuals with a functionally unstable ankle. *Physical Therapy in Sport*, 6(4), 181-187. doi: 10.1016/j.ptsp.2005.08.003

DeLahunt, E., Coughlan, G., Caulfield, B., Nightingale, E., Lin, C. & Hiller, C. (2010). Inclusion criteria when investigating insufficiencies in chronic ankle instability. *Medicine and Science in Sports and Exercise*, doi:10.1249/MSS.0b013e3181de7a8a

Donovan, L., Hart, J., Saliba, S., Park, J., Feger, M., Herb, C. & Hertel, J. (2016). Rehabilitation for chronic ankle instability with or without destabilization devices: A random controlled trial. *Journal of Athletic Training*, 51 (3) 233-251. doi: 10.4085/1062-6050-51.3.09

Eils, E., & Rosenbaum, D. (2001). A multi-station proprioceptive exercise program in patients with ankle instability. *Medicine and Science in Sport and Exercise*, 33(12), 1991-1998. doi: 0195-9131/01/3312-1991/$3.00/0

Fong, D., Hong, Y., Chan, L., Yung, P., & Chan, K. (2007). A systematic review on ankle injury and ankle sprain in sports. *Sports Medicine*, 37 (1), 73-94. 0112-1642/07/0001-0073/$44.95/0

Freeman, M., Dean, M., & Hanham, I. (1965). The etiology and prevention of functional instability of the foot. *Journal of Bone and Joint Surgery*, 47, 678-685.

Garrick, J. (1977). The frequency of injury, mechanism of injury, and epidemiology of ankle sprains. *American Journal of Sports Medicine*, 5, 241-242.

Gauffin, H., Tropp, H., & Odenrick, P. (1988). Effect of ankle disk training on postural control in patients with functional instability of the ankle joint. *International Journal of Sports Medicine*, 9,141-144.

Gribble, P., Delahunt, E., Bleakley, C., Caulfield, B., Docherty, C., Fourchet, F., … Wikstrom, E. (2013). Selection criteria for patients with chronic ankle instability in controlled research: a position statement of the international ankle consortium. *Journal of Orthopaedic and Sports Physical Therapy*, 43(8), 585-591. doi: 10.2519/jospt.2013.0303

Harrison, N. (2018). *The influence of HUMAC training on balance and range of motion in an Achilles tendon repair patient: A case study* (Unpublished master’s thesis). Florida Southern College of Exercise Science, Florida.

Hale, S., Hertel, J., & Olmsted-Kramer, L. (2007). The effect of a 4-week comprehensive rehabilitation program on postural control and lower extremity function in individuals with chronic ankle instability. *Journal of Ortheopaedic and Sports Physical Therapy*, 37(6), 303-311. doi:10.2519/jospt.2007.2322

Hertel, J. (2000). Functional instability following lateral ankle sprain. *Sports Medicine*, 29(5), 361–371. doi: 0112-1642/00/0005-0361/$20.00/0

Hertel, J. (2002). Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *Journal of Athletic Training*, 37(4), 364-375.

Hoffman, M. & Payne, G. (1995). The effects of proprioceptive ankle disk training on healthy subjects. *Journal of Orthopedic & Sports Physical Therapy*, 21(2).

Holme, E., Magnusson, S.P., Becher, K., Bieler, T., Aagaard, P. & Kjaer, M. (1999). The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. *Scand J Med Sci Sports* 9, 104-109.

Kannus, P., & Renstrom, P. (1991). Treatment of acute tears of the lateral ligaments of the ankle. Operation, cast, or early controlled mobilization. *Journal of Bone and Joint Surgery*, 73, 305-312.

Kaminski, T., Buckley, B., Powers, M., Hubbard, T., & Ortiz, C. (2003). Effect of strength and proprioception training on eversion to inversion strength ratios in subjects with unilateral functional ankle instability. *British Journal of Sports Medicine*, 37, 410–415.

Koltermann, J., Gerber, M., Beck, H., & Beck, M. (2017). Validation of the HUMAC balance system in comparison with conventional force plates. *Technologies*, 5(44). doi:10.3390/technologies5030044

Konradsen, L., Bech, L., Ehrenbjerg, M., & Nickelsen, T. (2002). Seven years follow-up after ankle inversion trauma. *Scandinavian Journal of Medicine & Science in Sports*, 12, 129-135. doi.org/10.1034/j.1600-0838.2002.02104.x

Konradsen, L., Magnusson, P. (2000). Increased inversion angle replication error in functional ankle instability. *Knee Surgery, Sports Traumatology, Arthroscopy*, 8, 246–251.

Le Clair, K., & Riach, C. (1996). Postural stability measures: what to measure and for how long. *Clinical Biomechanics*, 11, 176–178. doi:026%0033196

Lee, K., Lee, H., Kim, S., Choi, P., Song, S., & Jee, Y. (2012). Short term rehabilitation of ankle instability. *International Journal of Sports Medicine*, 33(6), 485-495. doi: 10.1055/s-0032-1301933

Lee, A. & Lin, W. (2008). Twelve-week biomechanical ankle platform system training on postural stability and ankle proprioception in subjects with unilateral functional ankle instability. *Clinical Biomechanics*, 23(8). doi:1065-1072.10.1016/j.clinbiomech.2008.04.013

Linens, S., Ross, S., & Arnold, B. (2016). Wobble board rehabilitation for improving balance in ankles with chronic instability. *Clinical Journal Sport Medicine*, 26(1), 76-82.

Linens, S., Ross, S., Arnold, B., Gayle, R., & Pidcoe, P. (2014). Postural-stability tests that identify individuals with chronic ankle instability. *Journal of Athletic Training*, 49(1), 15-23. doi: 10.4085/1062-6050-48.6.09

Manfroy, P., Ashton-Miller, J., & Wojtys, E. (1997). The effect of exercise, prewrap, and athletic tape on the maximal active and passive ankle resistance to ankle inversion. *The American Journal of Sports Medicine*, 25(2), 156-163. doi: 0363-5465/97/2525-0156$02.00/0

Matsusaka, N., Yokoyama, S., Tsurusaki, T, Inokuchi, S., & Okita, M. (2001). Effect of ankle disk training combined with tactile stimulation to the leg and foot on functional instability of the ankle. *American Journal of Sports Medicine*, 29(1), 25-30. doi: 0363-5465/101/2929-0025$02.00/0

Mattacola, C., & Dwyer, M. (2002). Rehabilitation of the ankle after acute sprain or chronic instability. *Journal of Athletic Training*, 37(4), 413-429. doi: 10.1177/0363546505284191

McKeon, P., & Mattacola, C. (2008). Interventions for the prevention of first time and recurrent ankle sprains. *Clinical Sports Medicine*, 27(3), 371-382. doi:10.1016/j.csm.2008.02.004.

Osborne, M., & Rizzio, T. (2003). Prevention and treatment of ankle sprain in athletes. *Sports Medicine*, 33(15), 1145-1150. doi: 0112-1642/03/0015-1145/$30.00/0

Payne, K., Berg, K., & Latin, R. (1997). Ankle injuries and ankle strength, flexibility, and proprioception in college basketball players. *Journal of Athletic Training*, 32(3), 221-225.

Smith, R., & Reischl, S. (1986). Treatment of ankle sprains in young athletes. *American Journal of Sports Medicine*, 14, 465-471.

Soderberg, G., Cook, T., Rider, S., & Stephenitch, B. (1991). Electromyographic activity of selected leg musculature in subjects with normal and chronically sprained ankles performing on a BAPS board. *Physical Therapy*, 71(7), 514-522.

Torg, J. (1982). Athletic footwear and orthotic appliances. *Clinical Sports Medicine,* 1, 157-175.

Tropp, H., Askling, C., & Guilquest, J. (1985). Prevention of ankle sprains. *American Journal of Sports Medicine*, 13(4), 259-262.

Van Rijn, R., Van Os, A., Bernsen, R., Luijsterburg, P., Koes, B., & Bierma-Zeinstra, S. (2003). What is the clinical course of acute ankle sprains? *American Journal of Medicine*, 121(4), 324-331. doi:10.1016/j.amjmed.2007.11.018

Verhagen, E., Van Der Beek, A., Twisk, J., Bouter, L., Bahr, R., & Van Mechelen, W. (2004). The effect of a proprioceptive balance board training program for the prevention of ankle sprains. *American Journal of Sports Medicine*, 32(6), 1385-1395. doi: 10.1177/0363546503262177

Wester, J., Jespersen, S., Nielsen, K., & Neumann, L. (1996). Wobble board training after partial sprains of the lateral ligaments of the ankle: a prospective randomized study. *Journal of Orthopaedic Sports Physical Therapy*, 23, 332-336.

Zouita, A., Majdoub, O., Ferchichi, H., Grandy, K., Dziri, C., & Salah, F. (2013). The effect of 8-weeks proprioceptive exercise program in postural sway isokinetic strength of ankle sprains of Tunisian athletes. *Annals of Physical and Rehabilitation Medicine*, 56, 634-643. doi: 10.1016/j.rehab.2013.08.003

2. BAPS TRAINING ON BALANCE

Ankle Injury Occurrence and Recurrence

Lateral ankle sprains are one of the most common musculoskeletal injuries in competitive and recreational athletes, thereby causing the most time lost from sport participation over any other sports related injury (Waterman, Owens, Davey, Zacchilli & Belmont, 2010). High school athletes experience roughly 5.2 ankle injuries for every 10,000 (either practice or competition) exposures (Nelson, Collins, Yard, Fields, & Comstock, 2007). These injuries are most common in sports such as soccer, volleyball, and basketball because they require sudden lateral movements, stops and pivoting (Eisenhart, Gaeta, & Yens, 2003). Unfortunately, a large percentage (20-74%) of individuals who experience lateral ankle injuries experience recurrent sprains for up to 6-18 months after initial injury (Braun, 1999; Freeman et al., 1965; Smith & Reischl, 1986; Torg, 1982). If not properly treated with rehabilitation, recurrent injuries are more likely to reoccur as long as 7 years after initial injury (Konradsen et al., 2002).

Residual symptoms commonly experienced after ankle inversion sprains are often described as a “giving way” feeling and are referred to as chronic ankle instability (CAI) (Delahunt et al., 2010). CAI symptoms are the result of damage to mechanoreceptors, muscles, ligaments, and the resulting joint hypermobility (Cain et al., 2017). CAI is often associated with impaired proprioception, decreased neuromuscular control, decreased range of motion (ROM), decreased strength, and altered gait (Donovan et al., 2016). Individuals who experience these injuries often attend physical therapy or a rehabilitation program to reduce CAI and the risk of recurrent sprains. These programs focus on reducing CAI by increasing joint stability, strength of ankle muscles (particularly in eversion), and proprioception/neuromuscular control (Cain et al., 2017). Researchers are still striving to determine the exact mechanisms that produce the best outcomes for injured individuals to reduce risks of CAI (Donovan et al., 2016). It is important that researchers strive to find ways to reduce the numbers of recurrent injuries, through effective rehabilitation protocols.

Inversion Injury Rehab Protocols

A variety of rehabilitation programs have been developed to assist in restoring ankle function after inversion sprains. Sports medicine professionals and researchers have developed ankle rehabilitation programs that primarily focus on two influential factors of CAI, strength of ankle musculature and proprioception (Blackburn et al., 2000).

Ankle rehabilitation programs commonly include proprioceptive exercises which reduce the risk of joint re-injury (Osborne & Rizzio, 2003). These proprioception-based programs often include single leg stance, balance, coordination exercises, and ankle disk training (Zouita et al., 2013). Ankle disk training consists of balance practice on unstable surfaces that require the individual to perform motions that gently challenge neuromuscular control of the foot and ankle (Mattacola & Dwyer, 2002). This training used tools including wobble board, rocker board, or biomechanical ankle platform system (BAPS). Ankle disk training tools have proven to increase postural awareness and decrease CAI symptoms (Osborne & Rizzio, 2003). These protocols also increase strength of lower extremity muscles by stressing muscles over the hip, knee, and ankle joints (Balogun et al., 1992). Several studies have directly compared the effectiveness of ankle sprain rehabilitation protocols.

One study reported a wobble board improved lower extremity strength and balance in healthy participants (Balogun et al., 1992). They found a significant increase in muscle strength (31-86%) and balance performance (20-85%) at the completion of the 6-week rehabilitation program. In another study, participants completed several different rehabilitative exercises including Therabands, hops, single leg stands on foam pads and BAPS over a 6-week period. This study found that semi-dynamic and dynamic balance increased 9.6-13.9% over 6 weeks but could not determine which exercise caused the increases (Blackburn et al., 2000).

A 4-week BAPS rehabilitation study found that completing clockwise and counterclockwise rotation significantly improved static balance by 49% (Cain et al., 2017). Destabilization devices are another tool used for ankle rehabilitation. In another study, participants completed a 4-week supervised rehabilitation program using destabilization devices (Donovan et al., 2016), there were no significant improvements in participants self-reported function, ROM, strength, balance, or EMG amplitude. Both researchers suggested that future studies should consider increasing the length of rehabilitation programs to 6-weeks instead of 4-weeks (Cain et al., 2017; Donovan et al., 2016) and identify the mechanisms that improve patient outcomes (Donovan et al., 2016).

Biomechanical Ankle Platform System

The Biomechanical Ankle Platform System (BAPS) is a well-known clinical rehabilitation tool used to increase lower extremity (particularly ankle) range of motion, and strength, as well as overall balance (Balogun, Pletcher, Miertschin, Martinez, & Hoeberlein, 1995). Training with BAPS on ankle injuries has shown improvements in patients' neuromuscular performance as well as enhanced stability of the affected joint (Lee & Lin, 2008). Emery, Cassidy, Klassen, Rosychuk, and Rowe (2005) reported that the use of a BAPS intervention on healthy high school basketball players resulted in improvements in static (80%) and dynamic (60%) balance with six weeks of training. Research studies have used the BAPS board to examine the magnitude and temporal features of the tibialis anterior, peroneus longus, and gastrocnemius muscle in subjects with normal and chronically sprained ankles (Soderberg et al., 1991). They found similar muscle activation in the tibialis anterior, peroneus longus, and gastrocnemius (20-80%) in normal and chronically sprained ankles.

Rehab Duration and Recurrence

Cain et al. (2017) recommended that further research should be conducted on the length of rehabilitation protocols to observe if balance improvements can be made after 4 weeks. The most common rehabilitation prescription is 12 sessions, 3 times a week for 4 weeks. Other research studies having evaluated the effectiveness of 6-10 week programs have found significant balance improvements (Adedoyin et al., 2008; Balogun et al., 1995; Emery et al., 2005; Holme et al., 1999; Mattacola & Dwyer, 2002). In a previous rehabilitative study using BAPS (Cain et al., 2017), participants trained 3 times a week for 4 weeks. The experimental group experienced significant improvements in static (49%) and dynamic balance (25%) when compared to the control group. Studies have also reported similar improvements with approximately equal training scheduled 2 times a week for 6 weeks (eversion: 22% inversion: 15%) (Holme, et al., 1999). Ankle sprains without rehabilitation can return to normal ranges (10-37%) within a year but still experience recurrent sprains (Zouita et al., 2013). With the inclusion of a BAPS program, recovery can be reduced to 4-8 weeks and reduce potential recurrent sprains. It is important to know if BAPS training beyond common clinical practice might improve function and further stabilize unstable ankles to perhaps beyond average, uninjured values to reduce the risk of recurrent sprains.

Purpose

The purpose of this research project was to evaluate if extending BAPS rehabilitation program from 4 to 6 weeks, would significantly increase participants' balance. Previous studies of BAPS rehab have focused on multiple training protocols over varying lengths. The study could confirm previous results of BAPS training and explore the exploratory hypothesis that longer (6-10 weeks) ankle inversion BAPS rehab protocols may result in an additional improvement in balance, theoretically reducing CAI and risk recurrent injury.

Methods

Following approval from the Institutional Review Board, participants were recruited from the student population at Texas State University. Students interested in participating in the study attended a familiarization session where they completed an informed consent, Activity of Daily Living (ADL) scales, and injury history prior to the collection of any pre-test data. All test and data collection were conducted by the researcher.

Participants

Participants for the study were students enrolled at Texas State University recruited from a large exercise physiology course and other responders to signs posted in Jowers academic building. Participants were asked to complete the ADL FAAM subscale and survey that classified them as either having a history of lower extremity injury or no history of injury. Volunteers were excluded from the study if they had an ankle sprain or other significant lower extremity injury in the last 60 days. Eighteen subjects were chosen for the study by random selection from the volunteers, four previously injured and fourteen uninjured participants. Participants had a mean age of 22 years old, a mean height of 65 inches, and a mean weight of 66 kg (Table 1). They represent the general population of college students with 56% Caucasian, 33% Hispanic and 11% African American. This sample size was selected using the G-Power 3.1 program (gpower.hhu.de) and allowed the detection of a 5% change in balance and statistical error rates of $\alpha < 0.05$ and $\beta < 0.20$. The provided minimum (n=16) sample size was exceeded. Participants in the study represented the general population of moderately active college students ranging in age from 19 to 31 years.

Protocol and Procedures

Familiarization sessions were scheduled for participants to teach the BAPS training program and how the pre and post-test would be conducted. Each participant's name, self-reported height and weight, age, sex, contact information, and injury history was recorded prior to collection of participants pre-test data. Following the pre-test data collection, participants began their 6-week training program supervised by the investigator (Non-dominant/ injured leg: 10 mins, 5 trials, 40 seconds per trial, alternating clockwise and counterclockwise every 10 seconds). Participants' progress was tested (Non-dominant/ injured leg: 1 practice trial, 3 measured trials, balancing for one minute on a HUMAC Balance platform) at 4-weeks and repeated again at 6-weeks. The best score of the 3 trials recorded for each test session was used for further analysis.

Instruments

The HUMAC Balance System (CSMi, Stoughton, MA) was used to measure static balance. Participants stood atop the platform on their non-dominant foot for 1 minute. The most commonly used balance variables measured by the HUMAC and force platforms are center of pressure (COP) excursions (Koltermann et al., 2017). Motion of the COP provides direct quantification of postural competence, based on ground reaction forces controlling body sway in stance. Two balance variables of COP motion were measured by the HUMAC Balance instrument during single leg stance trials with open eyes: COP width (in) and mean resultant COP velocity (in/sec).

BAPS board (Spectrum Therapy Products, MI) was the rehab exercise instrument used to complete the training program. It is a reversible platform with 5 hemisphere attachments (levels 1-5). Participants completed the program by slowly alternating rotations on their non-dominant/injured foot, clockwise and counterclockwise (level 3) with one-hand on a stable surface.

Analysis and Statistics

Descriptive statistics were calculated for all testing session scores and change scores. Two repeated measures ANOVAs were run with SPSS 25.0 (SPSS Inc, IL) to examine the change in balance scores across groups (injured, uninjured) and time (pre, 4-week, 6-week). A Holms correction was used to control for the inflation of the experiment-wise type I error rate set at $P<0.05$ for these ANOVAs. Dependent t-tests were performed when RMANOVA showed a significant effect for time. Sizes of changes were examined with effect sizes (d) and percentage change from pre-test values.

Results

Repeated measures ANOVAs revealed no effect ($p = 0.81$) of past ankle injury status for both balance variables. There was a significant effect for time ($F_{2,16} = 4.6$, p = 0.025 and ($F_{2,16} = 4.6$, p = 0.018) indicating balance improvements of BAPS training (Table 1). Post hoc dependent t-tests indicated there were significant improvements in both COP velocity ($p = 0.003$) and mean COP width ($p=0.007$) from the pre-test to 4-weeks of BAPS training. There were no significant differences in COP velocity ($p = 0.34$) and mean COP width ($p=0.35$) from 4-weeks to 6-weeks.

Discussion

After 4 weeks of BAPS training, participants experienced a significant change in both variables (velocity and width) indicating improved balance. Participants COP velocity decreased by 9.7% and width decreased by 8.9%. No main effect for injury status occurred, both groups experienced similar balance improvements. These improvements are comparable to those found in Donovan et al. (2016), whose 4-week destabilization training program resulted in 7.9% decrease in COP width, although no changes in COP velocity were observed. The current research study found smaller improvements (8.9-9.7%) than previous studies (25-50%) (Cain et al., 2017), but both support BAPS as an effective tool in improving balance. These differences may be due to different protocol or tools used to evaluate balance.

The hypothesis of additional improvements in both COP variables with two more weeks of training was not supported. While there were apparent trends in both variables (2.7-2.9%) to improve over time, the study failed to meet a research or clinical significance from week 4 to week 6. This could have been due to the sample size or error, future research should explore the option of longer periods of rehabilitation. Extending the program to 8-weeks may yield significant increases in both COP variables.

While there is limited research evaluating the COP function of the HUMAC balance system, previous research has found smaller widths traveled (25-45 mm) (Harrison, 2018) than the current study (45-99 mm). The velocity of the current study (0.77-1.65 mm/s) also varied from results provided from previous research (1.29-1.37 mm/s) (Harrison, 2018). While these numbers vary, they fall within the normal ranges found across multiple studies (Huurnink, Fransz, Kingma, & van Dieen, 2013; Smith, Ulmer, & Wong, 2012)

Limitations

Limitations to this study may include the size of the population (N=18). A future study with a larger population sampling may produce more significant increases in both variables. The length of BAPS rehabilitation programs may have limited the results, future studies should consider repeated measures with greater time between each measurement. Injury history report may also have been a limitation to this study, participants history was recorded via self-reported whereas functional test may have been more effective at diagnosing those with a history of injury.

Conclusion

This research study has further validated that this BAPS protocol is an efficient tool in ankle rehabilitation. Results from similar studies have revealed this 4-week program as effective in decreasing participants sway by decreasing their velocity and width traveled. Researchers should continue to study this rehabilitation protocol and the length at which it is most effective. Clinical settings should continue using this tool for training injured clients and reducing the risk of residual symptoms.

Table 1

Participants' Demographics

Variable	M	SD
Height (in)	65	3.33
Weight (kg)	66	13.68
Age (y)	22	2.67
BMI (kg/m^2)	24	4.02
Gender (%)		
Male	28	
Female	72	
Ethnicity (%)		
Caucasian	56	
Hispanic	33	
African American	11	

Note. Participant demographics were self-reported.

Table 2

Mean and Standard Deviation COP Variable Scores

	Velocity			Width		
Time of test	N	M	SD	N	M	SD
Pre-Test	18	1.13	0.27	18	67.8	16
Week 4	18	1.02*	0.18	18	61.2*	11
Week 6	18	0.99	0.22	18	59.5	13

Note. Velocity and width represented in mm/s and mm. * indicates significant (p<0.05) difference from pre-test.

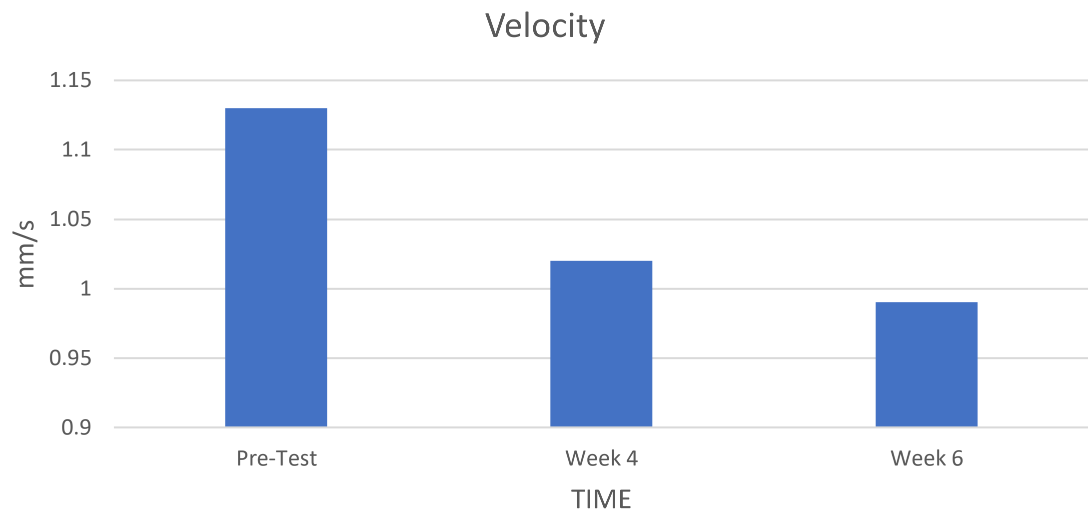

Figure 1. Mean COP Velocity Changes Over Time
Participants mean velocity at all three test times represented in mm/s. A significant increase occurs from Pre-Test to Week 4.

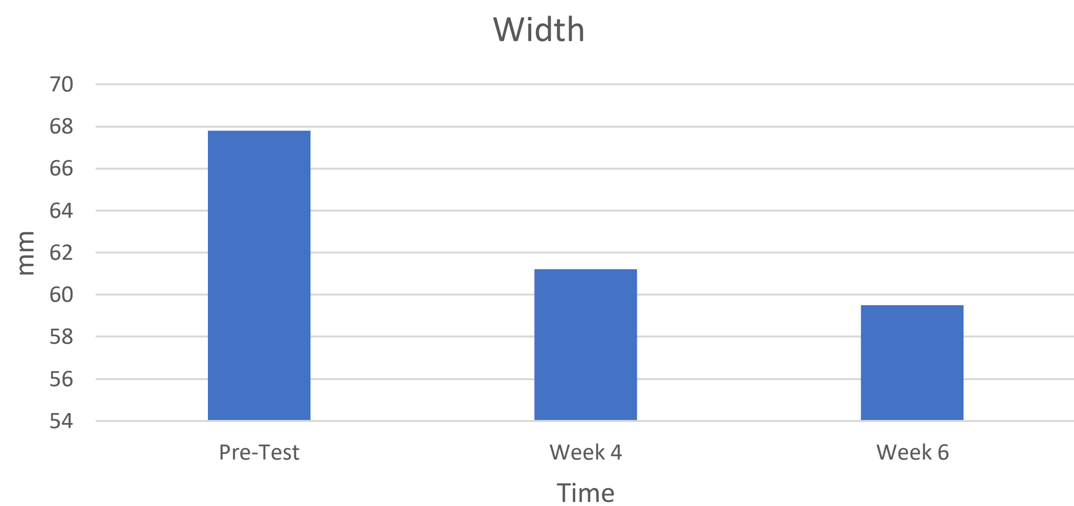

Figure 2. Mean COP Width Changes Over Time
Participants mean width at all three test times represented in mm. A significant increase occurs from Pre-Test to Week 4.

APPENDIX SECTION

Foot and Ankle Ability Measure (FAAM)

Activities of Daily Living Subscale

Please Answer **<u>every question</u>** with **<u>one response</u>** that most closely describes your condition within the past week.
If the activity in question is limited by something other than your foot or ankle mark "Not Applicable" (N/A).

	No Difficulty	Slight Difficulty	Moderate Difficulty	Extreme Difficulty	Unable to do	N/A
Standing	□	□	□	□	□	□
Walking on even Ground	□	□	□	□	□	□
Walking on even ground without shoes	□	□	□	□	□	□
Walking up hills	□	□	□	□	□	□
Walking down hills	□	□	□	□	□	□
Going up stairs	□	□	□	□	□	□
Going down stairs	□	□	□	□	□	□
Walking on uneven ground	□	□	□	□	□	□
Stepping up and down curbs	□	□	□	□	□	□
Squatting	□	□	□	□	□	□
Coming up on your toes	□	□	□	□	□	□
Walking initially	□	□	□	□	□	□
Walking 5 minutes or less	□	□	□	□	□	□
Walking approximately 10 minutes	□	□	□	□	□	□
Walking 15 minutes or greater	□	□	□	□	□	□

Literature Cited

Adedoyin, R., Olaogun, M., Omotayo, K., Olawale, O. & Egwu, M. (2008). Effects of wobble board training on weight distribution on the lower extremities of sedentary subjects. *Technology and Health Care*, 16, 247-253.

Balogun, J.A., Adesinasi, C.O. & Marzouk, D.K. (1992). The effects of a wobble board exercise training program on static balance performance and strength of lower extremity muscles. *Physiotherapy Canada*, 1992, 23, 332-6.

Balogun, J., Pletcher, E., Miertschin, D., Martinez, E. & Hoeberlein, T. (1995). Cardiovascular adjustments and perceived exertion during exercise on the BAPSr' board. *Disability and Rehabilitation*, 17(8), 430-436. doi: 10.3109/09638289509166657

Blackburn, T., Guskiewicz, K., Petschauer, M. & Prentice, W. (2000). Balance and joint stability: the relative contributions of proprioception and muscular strength. *Journal of Sport Rehabilitation*, 9, 315-328.

Braun, B. (1999). Effects of ankle sprain in a general clinic population 6 to 18 months after medical evaluation. *Archives of Family Medicine*, 1999, 8(2), 143– 148.

Cain, M. S., Garceau, S. W., & Linens, S. W. (2017). Effects of a 4-week biomechanical ankle platform system protocol on balance in high school athletes with chronic ankle instability. *Journal of Sport Rehabilitation, 26*(1), 1-7. doi: 10.1123/jsr.2015-0045

DeLahunt, E., Coughlan, G., Caulfield, B., Nightingale, E., Lin, C. & Hiller, C. (2010). Inclusion criteria when investigating insufficiencies in chronic ankle instability. *Medicine and Science in Sports and Exercise*, doi:10.1249/MSS.0b013e3181de7a8a

Donovan, L., Hart, J., Saliba, S., Park, J., Feger, M., Herb, C. & Hertel, J. (2016). Rehabilitation for chronic ankle instability with or without destabilization devices: A random controlled trial. *Journal of Athletic Training*, 51 (3) 233-251. doi: 10.4085/1062-6050-51.3.09

Eisenhart, A., Gaeta, T. & Yens, D. (2003). Osteopathic manipulative treatment in the emergency department for patients with acute ankle injuries. *Journal of American Osteopathic Association*, 103, 417-421.

Emery, C. A., Cassidy, J. D., Klassen, T. P., Rosychuk, R. J., & Rowe, B. H. (2005). Effectiveness of a home-based balance-training program in reducing sports-related injuries among healthy adolescents: a cluster randomized controlled trial. *Canadian Medical Association Journal*, 172(6), 749–754.

Freeman, M., Dean, M., & Hanham, I. (1965). The etiology and prevention of functional instability of the foot. *Journal of Bone and Joint Surgery*, 47, 678-685.

Harrison, N. (2018). *The influence of HUMAC training on balance and range of motion in an Achilles tendon repair patient: A case study* (Unpublished master's thesis). Florida Southern College of Exercise Science, Florida.

Holme, E., Magnusson, S.P., Becher, K., Bieler, T., Aagaard, P. & Kjaer, M. (1999). The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. *Scandinavian Journal of Medicine & Science in Sports*, 9, 104-9.

Huurnink, A., Fransz, D., Kingma, I., & van Dieen, J. (2013). Comparison of a laboratory grade force platform with a Nintendo Wii Balance Board on measurement of postural control in single-leg stance balance tasks. *Journal of Biomechanics*, 46, 1392-1395. All rights reserved. http://dx.doi.org/10.1016/j.jbiomech.2013.02.018

Koltermann, J., Gerber, M., Beck, H., & Beck, M. (2017). Validation of the HUMAC balance system in comparison with conventional force plates. *Technologies*, 5(44). doi:10.3390/technologies5030044

Konradsen, L., Bech, L., Ehrenbjerg, M., & Nickelsen, T. (2002). Seven years follow-up after ankle inversion trauma. *Scandinavian Journal of Medicine & Science in Sports*, 12, 129-135. doi.org/10.1034/j.1600-0838.2002.02104.x

Konradsen, L., Magnusson, P. (2000). Increased inversion angle replication error in functional ankle instability. *Knee Surgery, Sports Traumatology, Arthroscopy*, 8, 246–251.

Lee, A. & Lin, W. (2008). Twelve-week biomechanical ankle platform system training on postural stability and ankle proprioception in subjects with unilateral functional ankle instability. *Clinical Biomechanics*, 23(8). doi:1065-1072.10.1016/j.clinbiomech.2008.04.013

Mattacola, C., & Dwyer, M. (2002). Rehabilitation of the ankle after acute sprain or chronic instability. *Journal of Athletic Training*, 37(4), 413-429. doi: 10.1177/0363546505284191

Martin, R., Irrgang, J., Burdett, R., Conti, S., & Van Swearingen, J., (2005). Evidence of validity for the foot and ankle ability measure. *Foot and Ankle International*, 26 (11), 968-983.

Nelson, A., Collins, C., Yard, E., Fields, S., & Comstock, D. (2007). Ankle injuries among United States high school sports athletes. *Journal of Athletic Training*, 42(3), 381-387.

Osborne, M., & Rizzio, T. (2003). Prevention and treatment of ankle sprain in athletes. *Sports Medicine*, 33(15), 1145-1150. doi: 0112-1642/03/0015-1145/$30.00/0

Smith, R., & Reischl, S. (1986). Treatment of ankle sprains in young athletes. *American Journal of Sports Medicine*, 14, 465-471.

Soderberg, G., Cook, T., Rider, S., & Stephenitch, B. (1991). Electromyographic activity of selected leg musculature in subjects with normal and chronically sprained ankles performing on a BAPS board. *Physical Therapy*, 71(7), 514-522.

Torg, J. (1982). Athletic footwear and orthotic appliances. *Clinical Sports Medicine*, 1, 157-175.

Waterman, B., Owens, B., Davey, S., Zacchilli, M., & Belmont, P. (2010). The epidemiology of ankle sprains in the United States. *The Journal of Bone and Joint Surgery*, 92, 2279-2284. doi:10.2106/JBJS.I.01537

Zouita, A., Majdoub, O., Ferchichi, H., Grandy, K., Dziri, C., & Salah, F. (2013). The effect of 8-weeks proprioceptive exercise program in postural sway isokinetic strength of ankle sprains of Tunisian athletes. *Annals of Physical and Rehabilitation Medicine*, 56, 634-643. doi: 10.1016/j.rehab.2013