Effectiveness of a Proprioceptive Resistance Device in Changing Landing Style in Recreational Runners Learning to Land on the Ball of the Foot

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UNIVERSITY OF MIAMI

EFFECTIVENESS OF A PROPRIOCEPTIVE RESISTANCE DEVICE IN CHANGING LANDING STYLE IN RECREATIONAL RUNNERS LEARNING TO LAND ON THE BALL OF THE FOOT

By

Connie Sol

A DISSERTATION

Submitted to the Faculty
of the University of Miami
in partial fulfillment of the requirements for
the degree of Doctor of Philosophy

Coral Gables, Florida

December 2016

UNIVERSITY OF MIAMI

A dissertation submitted in partial fulfillment of
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Effectiveness of a Proprioceptive Resistance Device in Changing Landing Style in Recreational Runners Learning to Land on the Ball of the Foot (December 2016)

Abstract of a dissertation at the University of Miami.

Dissertation supervised by Professor Joseph F. Signorile.
No. of pages in text. (58)

Background: The recent trend in running entails changing from landing on the heels (RFS) to landing on the midfoot (MFS) or forefoot (FFS). This initiative is based on evidence showing a direct relationship between lower limb running-related injuries and heel-striking. Changing from RFS to MFS requires shortening the stride cycle. Studies exist showing biomechanical, neuromuscular, and physiological changes produced by shifting from RFS to MFS. These results are predominantly based on acute verbal instruction, provided either on a treadmill or overground, but we could find no controlled study comparing changes due to training in treadmill and overground running, or at submaximal and maximal speeds. Additionally, no study has quantified the impact of a resistive proprioceptive device coupled with training on changes in running style.

Objective: The purpose of this study was to examine the effectiveness of using a proprioceptive resistive device (EZRB) in concert with 6 weeks of Pose Method run training (PMRT) to convert RFS recreational runners to MFS by quantifying changes biomechanical, electromyographical (EMG) and physiological changes across different speeds and terrains.

Methods: Nineteen recreational runners were randomly assigned to one of three groups Controls (C: 4M, 1F, h = 1.78±0.1 m, mass= 78.6±14 kg, age = 51±5.5 y), drills

only (DO: 3M, 4F, h= 1.70±0.1 m, mass= 67.3 ±12 kg, age = 48±9.6 years), and drills plus belt (DB: 6M, 1F, h= 1.79±0.1 m, mass= 80±9.5 kg, age= 47±12 years). Subjects completed a maximum oxygen uptake (VO_{2MAX}) test on the initial testing day. On two subsequent days, they performed a submaximal test on treadmill, and submaximal and maximal tests on a 2 x 200 m measured overground course. After six weeks of training they repeated the 3-day test battery. Cardiopulmonary ergometry was used to collect cardiovascular measures (VO_{2MAX}, RER, HR) and oxygen cost (COST) and HR at lactate threshold (HR_{LT}) were computed. Kinovea video analysis was used to measure knee flexion (KFA) and dorsiflexion (DFA) angles, insoles were used to measure ground contact for cadence and stride length (CAD, SL), surface EMG was used to quantify use of the right leg rectus femoris (RF), vastus lateralis (VL), biceps femoris (BF), semitendinosus (ST), and lateral gastrocnemius (LG), and a timing system was used to determine performance time (TP) during overground trials. Mixed-design ANOVAs were conducted to determine differences across the training period and between groups.

Results: A significant difference in gait shift from RFS to MFS was observed between the C and treatment groups. On the treadmill both intervention groups increased CAD_{TM85} (DO(p=.003), DB(p=.039) and decreased DFA_{TM85} (DO (p=.039), DB (p=.029)); while overground DO decreased RER_{OUT85} (p=.039), RER_{OUTMAX} (p=.025), DFA_{OUT85} (p=.019) and DFA_{OUTMAX} (p=.013). DO also increased RF_{TM85} activity, while DB decreased in this variable enough to significantly differentiate DB from other groups (p=.042). Within group changes for C included an increase HR_{LT} (p=.028), and RER_{OUT85} (p=.011); for DO a decrease in TP_{OUT85} (p=.045), KFA_{OUT85} (p=.001), DFA_{TM85} (p=.001), DFA_{OUT85} (p=<.001), and increases in RF_{OUT85} (p=.045), BF_{OUT85} (p=.008),

ST_{TM85} (p=.004), and CAD_{OUT85} (p=.025); and, for DB an increase in BF_{TM85} (p=.008), BF_{OUTMAX} (p=.003), ST_{TM85} (p=.007), ST_{OUTMAX} (p=.015), CAD_{OUTMAX} (p<.001), and decreases in KFA_{OUTMAX} (p=<.001) and DFA_{OUTMAX} (p=.003).

Conclusion: Changes in biomechanics, cardiovascular responses, timed performance and muscle activations observed in the DO and DB at the different run conditions indicate a significant shift from RFS to MFS after 6 weeks of PMRT instruction, unique effectiveness of the proprioceptive device could not be established, but differences warrant further investigation.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deepest gratitude and appreciation to my advisor Dr. Joseph F. Signorile for his dedication to getting this project completed. This study might not have seen completion without his constant encouragement and guidance during the times of frustration. But we got it done. Thank you.

I would also express my gratitude to Dr. Moataz Eltoukhy for his input in processing EMG data and to him and the rest of my dissertation committee, Dr. Christopher Kuenze and Dr. Michael Baraga, for coming through and allowing me to defend with a very short notice. To Jackie Junco, Afton Seeley and Ben O'Brien, my ready-at-the-break-of dawn crew, my most sincere appreciation, given that without their support and contributions the testing sessions would not have been possible. A heartfelt thank you goes to the rest of my grad student colleagues at the Max Orovitz Lab, Kirk, Mel, Anoop, and the rest, who at one time or another were of crucial help with their knowledge.

Finally, to Dr. Nancy Klimas, my mentor and friend for a great part of this journey, thank you for your constant reminders and encouragement to stay and finish the process. I did.

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CHAPTER 1

INTRODUCTION

The principal components of human running gait are the stance phase and the swing phase, where time on the ground and time in the air, respectively, are the principle determinant.[1] Variations in running biomechanics (i.e. foot strike pattern, limb swing, joint flexion), whether planned (voluntary) or unplanned (genetics), affect the time component of the stance phase/swing phase relationship and result in concurrent variations in style of landing/running.

Running style uses factors such as stride length, stride rate, and support time to describe running techniques.[2] While each runner employs a unique running style, and the components defining that style tend to vary, running style classifications are typically defined by how the foot initiates contact with the ground. The three predominant running styles are: rearfoot strikers (RFS: landing on the heel), mid-foot strikers (MFS: landing on the ball of the foot), and forefoot strikers (FFS: landing on the toe area). RFS is the most prevalent running style, used by approximately 69% to 90% of all recreational runners, followed by MFS, with FFS being the least common.[1,3-11] For the purpose of this paper, unless otherwise specified, mid-foot runners are considered runners landing on the balls of their feet.[12]

The biomechanical descriptors of RFS are landing with the foot in front of the knee, with the knee extended, and with the ankle in dorsiflexion.[6,8,11] Biomechanical descriptors of MFS include: landing with body weight towards the front of the foot, on or close to the ball of the foot, with the heel lightly contacting the ground without any bodyweight; a greater knee flexion than RFS, and a plantar flexed ankle. In addition, RFS

produces greater vertical oscillation, greater stride length and lower cadence than MFS, with MFS runners spending a shorter time in the support phase than RFS.[7,12-15]

Impact created by landing of body weight generates ground reaction forces (GRF), the forces exerted on a body during the support phase of the running stride.[16,17] GRFs have three components of which the vertical component (VGRF) is the largest and accounts for the acceleration of the body's center of mass in the vertical direction.[17-19] Each landing style evokes a particular footstrike pattern. When VGRFs are plotted against time, the graph for RFS typically exhibits two force peaks, one resulting from the braking force at the initial impact and the second from the propulsive force prior to toe off (Figure 1.1A).[8,17,19] In contrast, MFS is characterized by an attenuated initial impact VGRF peak compared to RFS, likely due to greater compliance at the knee and ankle (Figure 1.1B).[17,19]

The rate at which the impact peak is reached (body weight over time) as shown in Figure 1.1, termed the loading rate, is related to stride biomechanics,[20-22] is particular to the type of landing,[17,19,23-25] and running speed.[19,26] Studies comparing VGRF and loading rates between RFS and MFS have reported that RFS evokes a greater impact to the landing structures due to a decreased knee flexion angle.[6,13,27,28] It has been argued that this indication of stress elevates the potential for injury due to poor shock absorption and limited force distribution.[29-33] In fact, as a number of reviews on etiology of running injuries note the relationship between GRF and overuse injuries [5,16,17,26,34] others take it further and link them to particular running styles.[6,7,21,22,35]

Stride length and stride frequency are biomechanical determinants of landing mechanics directly related to the generation of VGRF as established in studies conducted

by Chumanov et al[36] and Heiderscheit et al[37] as well as by earlier studies.[38,39] Furthermore, stride length, governed by the degree of knee flexion angle at impact, is generally regarded as the dominant shock attenuator of VRGF as measured by the degree of loading experienced at the knee joint.[22,29,37] Extending the angle of the knee joint at landing (decrease in knee flexion), equals an increase in stride length, which translates into a greater impact at landing from resultant VGRF.[28,39] MFS and FFS runners demonstrate lower VGRF and reduced VGRF loading rate than RFS, with a main biomechanical difference being a greater knee flexion at landing for RFS.[13,22] As described by Romanov[12]: the further forward a runner's foot lands from a vertical line at the hip (knee joint at a decreased flexion, ankle joint at an increased dorsiflexion), the greater the VGRF at the heel; while the closer the foot lands to that vertical line (knee joint is at an increased angle, ankle is in increased plantarflexion), the more the runner contacts the ground towards the front of the foot.

Stride length and stride frequency are inversely related to each other. Stride frequency for the purposes of this paper is cadence of running as measured in steps x minute. Changes in cadence provoke changes in stride length, which translates in changes in VGRF generated at impact. Studies analyzing the biomechanical consequence of cadence changes on impact forces at various joints reported decreases in impact forces and increases in energy absorption when step rate was increased by at least 10% over a self-selected cadence.[35-37,40,41] In running literature, while cadence refers to the number of times a foot strikes the ground in a given period, there are various terms used interchangeably with cadence. A 2014 systematic review of studies looking at stride frequency and stride length influence in running mechanics established that step

frequency, stride rate, stride frequency and step rate are commonly used interchangeably to reflect cadence in steps • minute^{-1}.[25]

Running economy (RE) is the standard measure of how well a runner uses his or her aerobic fuel sources at varying levels of performance.[42-45] RE is also correlated with variations in stride length and cadence.[11,40,46-48] When the influence of landing styles on RE was measured comparing RFS and MFS, the results were equivocal.[49] Some found that the shorter stance phase associated with increased cadence in MFS increased RE,[50,51] while other researchers either provided inconclusive results[14,24,51] reported that RFS runners were more economical at submaximal speeds [49] and longer distances. [41]

Assessments of muscle utilization patterns using electromyography (EMG) are key to a comprehensive analysis of gait. An EMG study by Cappellini et al [52] examined the activation patterns of selected muscles during walking and running at increasing speeds. Their results indicated that differences in firing patterns in the rectus femoris (RF), vastus lateralis (VL), biceps femoris (BF), semitendinosus (ST) and gastrocnemius (LG) could provide insight into the impact of changing running styles on patterns of use for these muscles. Chumanov et al [36] also examined changes in muscle activation patterns due to cadence. They determined that running with a step rate 5-10% faster than subjects' self-selected cadence can substantially lower the impact felt at the ankle, knee, and hip joints due to the biomechanical changes that take place at ground initial contact, supporting the concept that the firing of these muscles was modulated by changes in running styles. Higashihara et al[53] measured activity of hamstring muscles while increasing running speed but did not differentiate landing styles. There are no known

EMG studies measuring activity of hamstring muscles during submaximal and maximal overground running or on treadmill comparing RFS and MFS.

Based on the positive implication of attenuation of running related injuries that comes with running MFS over RFS there is a trend towards changing from running RFS to MFS or FFS. A quick internet search on popularity of MFS and FFS running yielded hundreds of thousands of entries along with many suggestions as to how to achieve the change. Successful instruction to change running form has relied on teaching methods that have a proprioceptive component and are designed to produce changes in neuromuscular patterns through repetition of specific drills such as described by Jeffreys[54]. In order to change running form, it must be considered a skill where successful performance depends on practicing proper execution. In the latter article that addressed effective motor learning, Jeffreys[54] described using drills where an activity, such as running, is deconstructed into specific target movement patterns, starting from the simplest and advancing to more complex patterns once the simple patterns are mastered. The Pose Method of Running Technique (PMRT), a method developed to change runners from RFS to MFS, applies this methodology as part of its teaching process, deconstructing the MFS run gait into drill sequences of increasing complexity and targeting proprioception.[12] For example, during PMRT instruction, after every drill set, the runner is asked to provide feedback on their perception of lower limb location and the instructor makes appropriate corrections to reflect the desired Pose position.

Changing running styles is not easily accomplished, therefore, drills may be supplemented with the use of proprioceptive aids such as the EZ Run Belt (EZRB) that can physically alter leg position during the swing time phase. The EZRB is a belted

device that uses bungee cords attached to hip and ankle straps (Figure 1.2A) to control leg swing and promote landing on the ball of the foot (Figure 1.2B). It was specifically designed as a teaching aid to induce the foot to land under the body's general center of mass.[12]

There are no proprioceptive resistive devices that have been proven to facilitate changing from RFS to MFS. Therefore, this study will be the first to examine the effectiveness of a proprioceptive device, the EZRB, as a teaching aid used in concert with PMRT to convert a sample of RFS recreational runners to the MFS running style while at the same time recording the changes in lower limb muscle activity, biomechanics, timed performance, and cardiovascular responses during 3 running conditions: at submaximal and maximal overground running as well as at submaximal on the treadmill.

CHAPTER 2

METHODS

Participants

G*Power software [55] was used to calculate an estimated sample size for the study, and, for a small effect size (0.25) based on conservative estimates, the recommended sample size was n=15. Considering that similar studies involving gait changes used between 10 and 45 subjects, the recommended *n* was within range. The final sample size recruited was n=32, with a post-attrition sample size of n=19.

Recruitment criteria for the study included: recreational male and female runners aged 20-65; running an average of 9-20 miles per week using heel striking running mechanics; apparently healthy, answering NO to all questions in Section I and Section II of the PARQ+ (Appendix C); is available to fulfill the time demands; achieving a minimum VO_{2MAX} in the FAIR range for their age and gender per the Cooper Institute's normative VO_{2MAX} tables (Appendix B). Participants were excluded if they: 1) answered yes to any of the PARQ+ questions; 2) incurred any injuries precluding them from running within last 6 months; 3) had any existing conditions that affected running gait; 4) had engaged in or were exposed to a formal run-training program to change their running gait within the past six months. Participants' demographics are presented in Table 2.0.

An Experimental Protocol Flow Diagram is presented in Figure 2.1 showing flow of participants through each stage of the study. Thirty-two participants were screened for eligibility and 1 was excluded for not meeting VO_{2MAX} criteria. Thirty-one participants were enrolled, 11 dropped out before completing pre-test phase, 1 control subject was excluded during post-testing, due to intentionally changing gait to forefoot landing.

Nineteen participants (13 males, 6 females; age 48.3 ±9.5 years, height 1.75 ±.09m, mass 75.0±12.4kg) completed the study. Table 2.0 also contains anthropometric information by gender and group. This investigation was approved by the University of Miami's Institutional Review Board for the Use and Protection of Human Subjects. The procedures and risks were thoroughly explained to the participants and their written Informed Consent was obtained prior to participation in the study

Instrumentation

Respiratory Gas Analysis and Cardiovascular Measures

Measures during all three testing procedures, before and after the training period, were collected using a Oxycon Mobile portable ergospirometry device (Jaeger, Carefusion Corporation, San Diego, CA). Breath-by-breath data including oxygen uptake relative to body weight (VO_2; $ml \cdot kg^{-1} \cdot min^{-1}$), and respiratory exchange ratio (RER) were averaged every 10s throughout the testing period. Heart rate was continuously measured using a Polar T31 Coded Transmitter (Polar Inc., Lake Success, NY, US), and transmitted via short-range telemetry to the Oxycon Mobile receiver. Prior to each testing session the Oxycon Mobile equipment was calibrated in accordance with manufacturer's instructions. Gas analyzers were calibrated using a certified gas mixture of 16% O2 and 4% CO2 and the airflow sensor was calibrated using the built-in automatic flow-volume analyzer.

Neuromuscular Electrical Stimulation (NMES)

Motor points of the five lower limb right side muscles were located using the Grass S88F Stimulator and SIU5B Stimulus Isolation Unit (Grass Technologies, Natus

Medical Incorporated, Warwick, RI, US). The following settings applied: average pulse per second (pps) 550; average delay 1.6μs (micro seconds); duration 5μs; volts adjusted to participant.

Maximal Voluntary Isometric Contraction (MVIC)

MVIC for normalization of EMG data was conducted: for the quadriceps group on the BIODEX System 2 (Biodex Medical Systems, Shirley, NY, US); for the hamstrings group on a Sammons Preston Value Line Treatment Table (Patterson Medical, Warrenville, Il, US).

Wireless Electromyography (EMG) and Gait Cycle Events

Muscle activities of five lower-limb right side muscles were measured during all testing procedures. using a Noraxon TeleMyo Direct Transmission System (DTS) telemetry system (Noraxon USA, Inc., Scottsdale, Arizona, US) with an input impedance of 100 Mohm, a common mode rejection ratio of 100 db, and gain set at 2,000. The system is composed of three components; the wireless DTS EMG Sensors, the DTS Belt Receiver, and the TeleMyo 2400 G2 Mini Receiver. Data were collected using the wireless DTS EMG Sensors at a frequency of 1.5KHz (1,500 samples•s^{-1}), and transmitted wirelessly to the TeleMyo 2400 G2 Mini Receiver which allows a wireless data acquisition range of up to 100 meters. Signals were digitized using a 16-bit A/D converter (Noraxon USA, Inc., Scottsdale, AZ, USA) and stored on a personal computer. In addition, left and right Noraxon Footswitch Insoles (Noraxon USA, Inc. Scottsdale, Arizona, US) were interfaced with the system to mark gait cycle events (cadence) and allow time sequencing.

Video Recording and Analysis

Video images were recorded during all test procedures using the JVC High Definition high-speed camera (Model No. GC-PX100BU) at 240 frames • s^{-1}. Subsequent frame x frame video analysis was performed using Kinovea software v. 0.8.15 (www.kinovea.org). Camera height was 65cm and distance from treadmill was 1.8m. Camera height was about125 cm and distance to subjects was about 8.5m during overground testing. While on the treadmill, an average of 20 seconds of video and EMG was simultaneously recorded at the last minute of each stage during each test condition. During overground running an average of 10-20 seconds of video and EMG was recorded at the second 200m of each test condition. Three strides were evaluated per treadmill test condition, two strides per overground condition, both at the initial point of contact at landing as determined via frame by frame analysis. Angle determinations were based on Damsted et al, [56] Ahn et al, [57] Tartuga et al, [41] and Kulmala et al . [22] Theoretical markers were placed at the greater trochanter, lateral femoral epicondyle, calcaneus and metatarsal heads (top of shoe) (Figure 2.2). To determine the knee flexion angle at initial contact, 180° lines were drawn through the greater trochanter and the calcaneus, through the greater trochanter and the lateral femoral condyle and through the femoral condyle and the calcaneus. Using the angle function at the femoral condyle marker, the knee flexion angle was calculated. For the dorsiflexion angle at initial contact, 180° lines were drawn from the calcaneus to the metatarsal heads and from the calcaneus along a line parallel with run surface, then, using the angle function at the calcaneus marker, determined the dorsiflexion angle. For overground the same procedure was adhered to

with the following differences: due to video limitations from obstacles: at times, only one stride cycle was available for analysis and sometimes the opposite leg was measured.

Field Test Timing

A Brower Timing System a wireless timing device (Brower Timing Systems, Draper, UT), was used for overground testing, which allows assessment and storage of overall and split times. The range of the system is approximately 300 m and the accuracy is to the thousandth of a second.

Cybex 750T Treadmill

Indoor treadmill testing utilized the Cybex 750T Treadmill (Cybex International, Medway, MA) with available running speeds ranging from 0.5 to 15.6 mph (0.8–25 kph), grades ranging from -3 to 15%, and a running surface measuring 22" W × 62" L (55 cm × 157 cm).

Testing Procedures

Day 1. Subjects arrived at the Max Orovitz Laboratory (MOLAB) to sign consent forms and perform the VO_{2MAX} test. Upon arrival, a researcher sat with subject, reviewed the Informed Consent and Authorization for Audio/video/Photography in a Research Study forms and once participant signed, proceeded to the preparation stage.

Preparation stage: EMG data were recorded during all testing procedures using 5 EMG electrodes placed on each of 5 muscles on right leg (RF, VL, BF, ST, LG). Clear measurements of muscle activity were indispensable to the study, therefore motor point location using NEMS was performed. Baseline locations were identified using Cram's Introduction to Surface Electromyography landmark guidelines. [58] To locate the motor

point with NEMS, we used the Grass S88F stimulator with the SIU5B Stimulus Isolation Unit (SIU) following Gobbo et al [59] recommendations to minimize subjects discomfort. Once identification of a motor point area occurred via landmarks the SIU was pressed on the specific area of skin overlying the target for 3 to 5 seconds, and if no contraction felt by subject and/or investigator, stimulation was repeated on adjacent areas until either a clear twitch was observed or a mechanical response was felt using manual palpation. As soon as the stimulation induced a contraction, the intensity was lowered, site was confirmed marked and electrode placed right over it.[59] All EMG electrodes were placed bilaterally on the skin overlying each motor point, which was shaved, abraded, and cleansed with rubbing alcohol according to Cram's [58] and SENIAM[60] recommendations. A bipolar electrode configuration, set parallel to the active fibers of the muscle, was used to maximize the reception area while controlling the potential for cross-talk from neighboring muscle groups. Locations were measured for landmarks and pictures taken for exact duplication of locations for all testing sessions. Noraxon Foot Switch Insoles replaced the subjects' running shoe insoles and electrodes placed on the lateral aspect of the right and left tibia following site preparation. Upon completion of electrode placement, subject was asked to walk around and jump up and down a couple of times to verify adhesiveness of electrodes, and to establish existence, clarity and strength of signals for all electrodes. Powerflex cohesive wrap (Andover Healthcare, Salisbury, MA, USA) was used to securely wrap and stabilize the wireless electrode leads at the prepared sites.

Following electrode placement, MVICs for use with normalization of EMG signals were conducted for each muscle group: Quads (RF, VL), Hamstrings (BF, ST),

and LG. Two good MVIC trials per muscle group with 1 minute rest in between were done. As per Contreras et al [61] it is important to use the MVIC position that elicits the strongest activation to decrease incidents of abnormally high normalized mean peak EMG data and thus increase the validity of the EMG outcomes. The Quad group MVIC was performed on a Biodex System 2 dynamometer (Biodex Corp., Shirley, NY). Based on studies of quadricep MVIC and position of knee flexion angle,[62] the Biodex would elicit a maximal contraction. Participants sat in an upright position with the hips in approximately 1.57 rad of flexion. The knee joint was aligned with the axis of rotation of the dynamometer and the dynamometer lever arm locked at 1.57 rad of knee flexion. The leg was secured to the dynamometer arm at the ankle using a Velcro strap. Additional straps across the thigh and the participant's chest were used to secure the participant to the dynamometer seat to minimize compensatory movements. Participants were asked to extend their leg against the dynamometer for 5s with as much force as possible. For the Hamstring group MVIC, the subject laid prone on the treatment table, pressed the hips downward, flexed right leg initially to 90° and maximally resisted as the tester pulled ankle towards themselves using body weight to extend the leg, decreasing the angle from 90° to closer to 60°. The greatest torque by the hamstrings is evoked when the knee flexion angle is at 60°. [61] The MVIC for the LG was performed standing on one leg, subjects were asked to perform a maximal plantar flexion, to raise themselves towards the toes as high as possible and to hold the contraction for 5 seconds. Unilateral isometric maximum plantar flexion contractions tend to evoke the strongest MVIC. [63]

Upon completion of MVIC cycle, the participant was outfitted with the Oxycon Mobile for the assessment of VO_{2MAX} using a Modified Bruce incremental protocol to

confirm that they met minimum cardiovascular fitness levels. The subject warmed up at a comfortable jogging speed for 5 minutes, then speed was increased by 1.0 mph for one minute and subsequently the grade was increased 1% per minute. An RPE scale was used to measure effort. Testing continued until volitional fatigue; however, if subjects did not voluntarily terminate the test and ACSM criteria for ending the test were reached, the test was terminated based on two of the four following criteria: 1) Plateau in VO_2 despite an increase in workload; 2) Heart rate within 10-15 beats per minute (bpm) of age-predicted maximum; 3) RER greater than 1.10; or, 4) Decrease in cadence below 80rpm. Cardiorespiratory data were collected continuously and EMG, footstrike, and video analysis data was collected during the middle 20 seconds of each stage. At the completion of test, VO_{2MAX} was determined for inclusion and if subject qualified, lactate threshold heart rate (HR_{LT}) was determined to prepare for submaximal testing on Day 2.

Day 2. Subjects returned to the lab for a continuous submaximal VO_2 test based on the HR_{LT} determined on Day 1. The test was comprised of 3 consecutive and continuous incremental stages of 5 minutes each (or until steady state was reached and held for at least 2 minutes) each stage was based respectively on 65%, 75% and 85% of the heart rate achieved at HR_{LT}, allowing a ±10% range in HR each stage.

Day 3. Subjects repeated the same pre-test procedures as Day 1 and Day 2. Following preparation, participants moved to a 2 x 200m outside measured course. The test incorporated a continuous 4 x 400m run divided into 400m consecutive stages at 65%, 75%, and 85% HR_{LT} (same as Day 2) and maximal effort respectively. The subject was provided with a heart rate watch to self-regulate pace while investigator also monitored HR wirelessly. Timed collection of cardiorespiratory data occurred throughout

the test, and on the 2nd lap of each stage for EMG. Video recordings for footstrike and kinematic data were also collected during second lap of each stage. Total performance time and split times were recorded using an infrared timing system (Brower Timing System, Draper, UT). After completion of Day 3 subjects were randomly assigned to one of three training groups. Subjects assigned to wear the EZRB received them on Day 3, along with proper fitting and instructions on utilization.

Training Intervention

Participants were randomly assigned to one of three training groups, drill only (DO), drill with the EZRB (DB) and controls (C). Subjects in Groups DO and DB met 6 times at various locations for a weekly 1- hour drill session. A total of 20 drills were taught from the PMRT Companion Drill Book [64] (Appendix D) using a format where each drill was repeated 3 to 4 times and corrections in form were provided at the end of each repetition. At the beginning of each training session participants were asked about their weekly training mileage and experience, and then told to warm up by jogging for approximately 5 minutes to get a sense of what their body was doing. At the end of the warm up, individual specific verbal feedback on MFS form deviations was given by instructor. At start of the drill session, the drill set from prior days was practiced 3 to 4 times with corrections, then the new drills set taught during the session followed same procedure. After each individual drill repetition was completed, each subject ran a 10 to 20-meter distance and then were asked to verbally explain how their run felt at the end of the drill, compared to when they first warmed up. The objective was for the participant to develop proprioception and for the instruction to customize the verbal drill instruction to the participant. Both interventions groups were instructed to practice the drills prior to

and during their regular run sessions for the duration of the 6-week drill teaching period, DB group was additionally instructed to wear the EZRB during all their run training sessions but not during the weekly drill instruction session.

Statistical Analysis

Individual mixed designed repeated measures analyses of variance (ANOVA) were conducted for each dependent variable to evaluate any significant time differences or time and group interactions. When significant group x time interactions were detected, Bonferroni pairwise comparisons were used to identify the source. The model contains 3 independent variables (C, DO, DB), 2 time factors (Pre, Post) and 36 dependent variables, listed in Tables 3.1 to 3.6. Because the number of samples (n) varied among the variables tested, separate analyses were performed for each dependent variable. All analyses were performed using SPSS 23 Gradpack Standard Statistical Software package (IBM corp., New York, NY). Alpha level was set *a priori* at $p \leq 0.05$.

CHAPTER 3

RESULTS

All acronyms used in this chapter are defined in Appendix A.

Cardiovascular Measures

Adjusted mean differences, standard errors, and significance levels for all cardiovascular measures are presented in Table 3.1.

Maximum Oxygen Uptake(VO_{2MAX}), Maximum Heart Rate(HR_{MAX}), Lactate Threshold Heart Rate(HR_{LT})

There were no significant main effects or interactions for VO_{2MAX} or HR_{MAX}. There was a significant time x group interaction for HR_{LT} with a large effect size ($F_{(2,16)}$ =4.358, p=.031, η_p^2=.353). Pairwise analyses of changes across the training period revealed a significant increase for the C group with a large effect size ($F_{(1,16)}$ =5.801, p=.028, η_p^2=.266) and a decline for the DB group that while not statistically significant (M_{diff} ±SE: -3.86±2.25, CI95% (-8.6, .904)) demonstrated a medium effect size ($F_{(1,16)}$ =2.950, p=.105, η_p^2=.156).

Running Economy(COST)

There were no significant time x group interactions for $COST_{TM75}$ or $COST_{TM85}$. Subsequent pairwise analysis using a Bonferroni adjustment for $COST_{TM75}$ revealed an increase in oxygen cost that was not statistically significant (M_{diff} ±SE:.121±.07, CI95% (-.023,.265)) with a small effect size for DO ($F_{(1,16)}$ =3.165, p=.094, η_p^2=.165).

Moreover, post hoc tests determined a significant difference between the C and the DO groups (M_{diff} ±SE:.25±.08, p=.020 CI95% (.036,.46)); but not between C and DB or between the two intervention groups. Pairwise comparisons using a Bonferroni adjustment for $COST_{TM85}$ revealed an increase in oxygen cost that was not statistically significant but exhibited a medium effect size for the DO group (M±SE:.105±.05, CI95% (-.009, .218)) ($F_{(1,16)}$ =3.843, p=.068, η_p^2=.194); but not for DB or C.

Respiratory Exchange Ratio(RER)

There were no time x group interactions for $RER_{TM75;}$ however, subsequent analyses determined there was a significant increase in DO with a concurrent medium effect size ($F_{(1,16)}$ =4.515, p=.05, η_p^2=.220), but no significant differences between the groups. There was a time x group interaction that was not statistically significant but revealed a large effect size for RER_{TM85} ($F_{(2,16)}$ =3.203, p=.068, η_p^2=.286). Further pairwise analysis for RER_{TM85} revealed a significant increase for DO (M±SE:.066±.02 CI95% (.019, .113)) with a large effect size ($F_{(1,16)}$ =8.836, p=.009, η_p^2=.356,); but no significant differences between the groups. There was a time x group interaction lacking statistical significance but exhibiting a large effect size for RER_{OUT85} ($F_{(2,14)}$ =3.374, p=.064, η_p^2=.325), further pairwise comparisons determined the C group experienced a significant decrease across the training period ($F_{(1,14)}$ =8.565, p=.011, η_p^2=.380, CI95% (.025, .165)). Significant differences were seen for RER_{OUT85} between C and DO (M_{diff} ±SE: -.13±.05, p=.039, CI95%(-.251, -.006)), but not between C and DB or DO and DB. There was also a time x group interaction that did not reach statistical significance but demonstrated a large effect size at RER_{OUTMAX} ($F_{(2,15)}$ =3.288, p=.065, η_p^2=.305). Further pairwise comparisons revealed a significant difference between DO and C (M_{diff} ±SE: -.15±.05 p=.025, CI95%

(-.282, -.017)), and a difference that just missed statistical significance between DB and C (M_{diff} ±SE: -.12±.05 p=.075, CI95% (-.26,.010)). No significant difference was seen between DO and DB. Pairwise comparisons of time changes revealed that the increase for the C group (M_{diff} ±SE: .097±.05 CI95% (-.006, 201)) did not reach statistical significance but exhibited a medium effect size ($F_{(1,15)}$ =4.032, p=.063, η_p^2=.212,).

Performance Time(TP)

There were no significant group or time effects, or time x group interactions for TP_{OUT85}; however, pairwise analysis found no significant differences between groups. There was a statistically significant time x group interaction with a large effect size for TP_{OUTMAX} ($F_{(2,15)}$ =7.117, p=.006, η_p^2=.471); no differences were found between groups during pairwise comparisons. Pairwise comparisons within groups did reveal the C group demonstrated a significant decrease in performance along with a large effect size ($F_{(1,16)}$ =6.826, p=.019, η_p^2=.299, CI95% (1.4,13.4)), while the DO group achieved a statistically significant improvement with a large effect size ($F_{(1,16)}$ =7.536, p=.014, η_p^2=.320, CI95% (-11.65, -1.5)). The DB group exhibited no significant change in performance.

Electromyographic Measures

Adjusted mean differences, standard errors, and significance levels for electromyographic measures are presented in Table 3.2 for the quadriceps, Table 3.3 for the hamstrings, and Table 3.4 for the lateral gastrocnemius.

Quadriceps

Rectus Femoris(RF)

There were no significant time x group interactions for RF_{TM85}; however, pairwise comparisons using Bonferroni adjustments for multiple comparisons revealed a statistically significant difference between DO and DB (M_{diff} ±SE: -.014±.005 p=.042, CI95% (.000, .029)). There was no significant time x group interaction for RF_{OUT85}. Pairwise analyses did reveal a statistically significant increase (M_{diff} ±SE:.03±.01 CI95% (.001, .052)) with a large effect size for the DO group ($F_{(1,7)}$ = 5.973, p=.045, η_p^2=.460). There was no significant time x group interaction for RF_{OUTMAX}. Pairwise comparisons did show an increase within the DO group (M_{diff} ±SE:.03±.01 CI95% (-.003, .033)) that while statistically not significant did demonstrate a medium effect size ($F_{(1,12)}$ = 3.863, p=.073, η_p^2=.244).

Vastus Lateralis(VL)

There were no significant time x group interactions nor any significant changes in muscle activity for VL_{TM85} and VL_{OUTMAX}. While there was no significant time x group interaction for VL_{OUT85}; there was an increase in amplitude that did not reach statistical significance, but exhibited a medium effect size for C group ($F_{(1,13)}$ = 3.198, p=.097, η_p^2=.197).

Hamstrings

Biceps Femoris(BF)

There were no significant time x group interactions for BF_{TM85}, but there was a statistically significant mean increase in muscle activity (M_{diff} ±SE:.016±.005, CI95%

(.005, .028)) with a large effect size for the DB group ($F_{(1,16)} = 9.038$, p=. 008, η_p^2=.361). There were no significant time x group interactions for BF_{OUT85}, but there were statistically significant increases of muscle activity by the DO group (M_{diff} ±SE:.041±.013, CI95% (.013, .068)), ($F_{(1,12)} = 10.096$, p=.008, η_p^2=.457) and DB (M_{diff} ±SE:.029±.012, CI95% (.003, .054)) ($F_{(1,12)} = 6.080$, p=.030, η_p^2=.336) groups, both also with large effect sizes. There were no significant time x group interactions for BF_{OUTMAX} but there was a statistically significant mean increase with a large effect size within the DB group (M_{diff}±SE:.044±.012, CI95% (.017,.070)) ($F_{(1,16)} = 12.244$, p=.003, η_p^2=.434).

Semitendinosus(ST)

There were no significant time x group interactions for ST_{TM85}. Subsequent pairwise analyses revealed statistically significant increases with large effect sizes in muscle activity for the DO (M_{diff}±SE:.064±.019, CI95% (.024, .105)) ($F_{(1,15)} = 11.318$, p=.004, η_p^2=.430) and DB (Mdiff±SE:.055±.018, CI95% (.017, .093)) ($F_{(1,15)} = 9.548$, p=.007, η_p^2=.389) groups. While there were no significant time x group interactions for ST_{OUT85} there was an increase in muscle activity that failed statistical significance for the DO group (M_{diff}±SE:.035±.018, CI95% (-.005, .075)) that still carried a medium effect size ($F_{(1,12)} = 3.666$, p=.080, η_p^2=.234). There was a time x group interaction that was not statistically significant but carried a large effect size for ST_{OUTMAX} ($F_{(2,11)} = 3.580$, p=.063, η_p^2=.394); however, subsequent pairwise comparisons failed to discover any significant differences among groups. A statistically significant mean increase in ST muscle activity (M_{diff}±SE:.017±.037, CI95% (.026, .189)) carrying a large effect size within the DB group was evidenced ($F_{(1,11)} = 8.367$, p=.015, η_p^2=.432).

Lateral Gastrocnemius

There were no significant time x group interactions for LG_{TM85}, LG_{OUT85} or LG_{OUTMAX}. Pairwise comparisons did reveal a statistically significant increase in activity for LG_{OUT85} for the DO group that exhibited a large effect size ($F_{(1,12)}$ =4.726, p=.050, η_p^2=.283).

Biomechanical Measures

Adjusted mean differences, standard errors, and significance levels for biomechanical measures are presented in Table 3.5 for cadence and stride length and Table 3.6 for knee flexion and dorsiflexion angles at initial contact.

Cadence(CAD)

There was no significant time x group interaction for $CAD_{TM85.}$ Pairwise comparisons determined that the cadence increases by the DO group did not reach statistical significance but carried a medium effect size ($F_{(1,15)}$ =3.732, p=.072, η_p^2=.199). Pairwise comparisons uncovered a statistically significant difference between the C and DO groups (M_{diff} ±SE: 9.5±2.3 p=.003, CI95% (3.3, 15.7)) and C and DB groups (M_{diff} ±SE: 6.5±2.3 p=.039, CI95% (.274, 12.7)) but not between the intervention groups. A statistically significant increase made by DB carried a large effect size ($F_{(1,15)}$ =7.536, p=.015, η_p^2=.334). There was no significant time x group interaction for CAD_{OUT85}. Pairwise analysis did reveal statistically significant increases within the DO (M_{diff} ±SE:.4.7±1.8, CI95%(.692,8.64)) ($F_{(1,13)}$ =6.432, p=.025, η_p^2=.331) and DB (M_{diff}±SE:5±1.8, CI95% (1,9)) ($F_{(1,13)}$ = 7.384, p=.018, η_p^2=.362) groups both with large effect sizes. Finally, there was a statistically significant time x group interaction for

CAD_{OUTMAX} with a very strong effect size ($F_{(2,15)}$ =11.836, p=.001, η_p^2=.612); however, subsequent pairwise comparisons failed to find any significant differences among groups. Analysis of within group changes found a statistically significant cadence increase for DB (M±SE:4.7±.69) ($F_{(1,15)}$ =47.084, p=<.001, η_p^2=.758) with a very strong effect size.

Stride Length(SL)

There was a statistically significant time x group interaction for SL_{OUTMAX} with a large effect size ($F_{(2,15)}$ =4.083, p=.038, η_p^2=.352), but no significant effects of time, group or interactions for $SL_{OUT85.}$ Additional pairwise analyses for SL_{OUTMAX} revealed a statistically significant decrease with a medium effect size for the C subjects ($F_{(1,15)}$ =4.737, p=.046, η_p^2=.240) and a decrease in stride length that did not reach statistical significance yet carried a medium effect size for the DB subjects ($F_{(1,15)}$ =3.450, p=.083, η_p^2=.187).

Knee Flexion Angle(KFA)

There was no significant time x group interaction for KFA_{TM85}, but there were statistically significant decreases within the DO group (M_{diff} ±SE: -5.4±1.7, CI95% (-9.1,-1.8)) ($F_{(1,14)}$ =10.094, p=.007, η_p^2=.419) and DB group (M_{diff} ±SE:-6.6±2, CI95% (-10.9, -2.3)) ($F_{(1,14)}$ =10.657, p=.006, η_p^2=.432) that carried a large effect sizes. There was a time x group interaction just missing statistical significance yet carrying a strong effect size for KFA_{OUT85} ($F_{(2,11)}$ =3.837, p=.054, η_p^2=.411); but pairwise comparisons revealed no differences among groups. A statistically significant decrease by DO (M_{diff} ±SE: -6.2 ±1.3, CI95% (-9, -3.4)) ($F_{(1,11)}$ =23.081, p=.001, η_p^2=.677) and one very close to statistical significance by DB (M_{diff} ±SE: -2.8 ±1.3, CI95% (-5.6, .040)) ($F_{(1,11)}$ =4.707, p=.053, η_p^2=.300) were evidenced which exhibited strong effect sizes. There was a

statistically significant time x group interaction with a large effect size for KFA_{OUTMAX} ($F_{(2,14)}$ =6.289, p=.011, η_p^2=.473); however, pairwise comparisons failed to discover any significant differences among groups. Within group comparisons revealed a significant decrease in knee angles at landing for the DO (M_{diff} ±SE: -5.6 ±1.9, CI95% (-9.6, -1.6)) ($F_{(1,14)}$ =9.018, p=.009, η_p^2=.392) and DB groups (M_{diff} ±SE: -7.7±1.6, CI95% (-11.1, -4.3)) ($F_{(1,14)}$ =23.958, p=<.001, η_p^2=.631) both with large effect sizes.

Dorsiflexion Angle(DFA)

There was a significant time x group interaction with a large effect size at DFA_{TM85} ($F_{(2,14)}$ = 5.645, p=.016, η_p^2=.446), Further pairwise comparisons revealed statistically significant differences between C and DO (M_{diff} ±SE: -10.4±3.6 p=.039, CI95% (-20.3, -.46)) and between C and DB (M_{diff} ±SE: -11.8±3.9 p=.029, CI95% (-22.5, -1.1)), but not between DO and DB. Additional pairwise analyses established statistically significance decreases with large effect sizes in dorsiflexion angle at landing within DO ($F_{(1,14)}$ = 15.971, p=.001, η_p^2=.533) and DB ($F_{(1,14)}$ = 15.856, p=.001, η_p^2=.531). There was a statistically significant time x group interaction at DFA_{OUT85} ($F_{(2,11)}$ =4.269, p=.042, η_p^2=.437). Pairwise analyses revealed a significant difference between the C and DO (M_{diff} ±SE: -14.1±4.2 p=.019, CI95% (-25.8, -2.3)), but not between C and DB (M_{diff} ±SE: -10.7±4.2 p=.080, CI95% (-22.4, 1.1)). Within group comparisons found statistically significant decreases with large effect sizes in dorsiflexion angle at initial landing for DO ($F_{(1,11)}$ =24.919, p=<.001, η_p^2=.694) and DB ($F_{(1,11)}$ = 12.452, p=.005, η_p^2=.531). There was a statistically significant time x group interaction for DFA_{OUTMAX} ($F_{(2,14)}$ =4.786, p=.026, η_p^2=.406). A significant difference between C and DO (M_{diff} ±SE: -15.6±4.6 p=.013, CI95% (-28, -3.2)) was detected, but not a non-significant

between C and DB (M_{diff} ±SE: -10.1±4.2 p=.093, CI95% (-21.6,1.3). Pairwise comparisons for DFA_{OUTMAX} showed significant decreases with large effect sizes for both DO (M_{diff} ±SE: -15.6±3.5, CI95% (-23.1, -8.1)) ($F_{(1,14)}$ =19.721, p=.001, η_p^2=.585) and DB (M_{diff} ±SE: -10.7 ±3, CI95% (-17.1, -4.3)) ($F_{(1,14)}$ = 13.023, p=.003, η_p^2=.482).

CHAPTER 4

DISCUSSION

To our knowledge this is the first study to examine the effectiveness of a proprioceptive device, the EZRB, as a teaching aid used in concert with a dedicated 6-week MFS running instruction (PMRT) to convert a sample of RFS recreational runners to the MFS running style. The effectiveness of the program, with and without the belt, was determined by examining changes in biomechanical, physiological, performance and EMG measurements. Both treatment groups, DO and DB, received the same instruction, comprised of repetitive PMRT drills [54] and verbal and visual feedback. [65]

Cardiovascular Measures

Cardiovascular Response, Running Economy, RER, Performance Time

The study hypothesis was a decrease in running economy based on increased work. The oxygen cost results for both steady state submaximal treadmill runs (HR_{TM75}, HR_{TM85}) in the current study were inconclusive, the increase in oxygen cost for the DO group approached significance at both efforts, while the C and DB groups showed small, albeit nonsignificant, decreases. Our results for running economy though, are in agreement with the study by Dallam et al [14] that change elite triathletes who used RFS to MFS using PMRT across a 12-week period. Although the desired biomechanical changes were achieved, including decreased mean stride length, increased stride frequency and decreased vertical oscillation, they were associated with an increase in oxygen cost. Our results should also be considered with the caveat that gender differences may have

affected them. Males tend to be more economical than females at a given running speed [66] and the DB and C Groups were mostly men while the majority of the runners in the DO were women.

RER, an established means for quantifying energy demands ,[67] was used to assess aerobic/anaerobic metabolic status at the end of each test session. The hypothesis expectations were an increase in RER and a decrease in performance times resulting from the PMRT training. As per Wasserman et al [68] conclusions, an increase in RER is directly related to increases in lactate, a by-product of increasing anaerobic demands such as could be attributed to increases in cadence or increases in time performance. In addition, there are studies pointing to alterations in stride lengths being associated with increased aerobic demands.[48] As expected, the DO group showed a significant increase in RER at the end of the submaximal treadmill run, concurrent with an increase in CAD_{TM85} but when running the overground trials, DO showed no significant changes in mean RER despite increases in cadence much like Kyröläinen et al [69] found during testing of endurance runners (non-differentiated landing style) at three submaximal speeds on the treadmill as well as the track. Meeting performance expectations, the DO lowered their finish times. The DB group did not show any changes in mean RER across all conditions, nor did they experience any improvements in performance, yet they significantly increased cadence across all 3 conditions. Thus, despite an increase in work that should have translated into a boost in RER, same as RE, it did not materialize. The C group, without significant changes in cadence in any condition, with a significant slower maximal performance but no control over training volume, displayed a significant increase in RER in both overground runs.

Electromyographic Measurements

EMG studies that examined differences between RFS and MFS vary widely in their scope and approach. They either compared natural RFS and natural MFS runners without changing style [57,70] or more commonly, examine the capacity of RFS to run using MFS or FFS style as an acute change during a single session. [71,72] Additionally, in studies where measurements were made using diverse testing environments like the current study, they failed to assess the effects of running style on EMG. For example, Montgomery et al [73] compared muscle activation pattern changes during overground, motorized treadmill and non-motorized treadmill running; but did not differentiate among running styles. Higashihara et al [53] measured BF and ST during overground at five submaximal speeds, however, these researchers did not examine variations in running style nor compare overground to treadmill running. A unique characteristic of our study as it relates to EMG analysis is that the overground testing was performed on a 2 x 200m measured flat course, rather than the 15-25m runways usually used for sprint and overground assessments.[74-76]

The five muscles chosen for this study are actively engaged during running [70,77,78] and the degree of engagement is influenced by running style. [70] The hypotheses for muscle activations were increases in all 5 muscles across all 3 conditions from the effects of PMRT training, such as an increased cadence. When transitioning the participants from RFS to MFS one of the strongest biomechanical changes was an increase in cadence.

When cadence is increased by 5-10% over preferred step rate, muscle activity may decrease due to a decrease in impact and load rate, but if speed concurrently

increases with cadence, all muscles would be expected to show an increase in activity except for the VL. [36,77,79] As expected, during treadmill running the rmsEMG of the VL (Table 3.2) did not show significant changes from pre-test values for the Controls or for the treatment groups despite increases in cadence. [36,70,77] In response to their cadence changes running on overground effort, the DO group's RF presented a statistically significant activity increase (M±SE:.026±.011, p=.045) at the submaximal as well as at the maximal effort (but not significant) (M±SE:.027±.013 p=.073). Contrary to expectations, the DB group did not show any significant changes in the quadriceps.

Post PMRT training, the DO group presented increases in hamstring muscle activation, but only achieved significance in the rmsEMG of the BF_{OUT85} and ST_{TM85}. The DO did increase speed of performance, directly related to increased BF activation consistent with the Higashihara et al [53] conclusion that increases in speed concurrently increase hamstring activations, a conclusion also supported by Kyröläinen et al.[79] The DB outcomes were as expected based on the studies referenced, displaying increases in both BF and ST activations (Table 3.3). Because the hamstrings activate in the mid to late swing phase, [36] and both groups demonstrated the greater knee flexion during anticipatory pre-activation in the late swing phase, consistent with PMRT training, [13] the end result was an expected increase in the amplitude of hamstring activity irrespective of terrain as per Riley et al. [80] In a treadmill to overground comparison study with a mixed group of runners (RFS, MFS, FFS) running at self-selected speeds, Riley et al [80] found no significant differences in kinetics and kinematics between the environments.

Activity of the LG was relatively small except for the DO group. While Yong et al [70] observed that LG activity would be expected to increase, and both intervention

groups did show small increases, only the DO group showed a significant amount of loading at the LG and only at the submaximal overground run. The PMRT biomechanical training effect decreasing DFA in both treatment groups, could have allowed a more neutral ankle position that may have elicited protection against LG overloading, especially as would be expected at the maximal effort.

Biomechanical Measurements

Knee Flexion and Dorsiflexion Angles at Initial Contact

All subjects in this study began as RFS runners, characterized by landing with the foot in front of an extended knee, a decreased knee flexion angle and the ankle in dorsiflexion at initial contact with the ground. [6,8,11] We hypothesized that the intervention groups would demonstrate successful MFS instruction in the most important run gait determinants including decreased knee flexion angles at initial landing, accompanied by decreases in dorsiflexion angles, [13,28] and subsequently establish the effectiveness of the EZRB as a tool. The literature points toward a tendency for a decreased KFA (greater flexed knee) at landing (at the late swing phase) during submaximal treadmill running, [80] as a marker of MFS (decreased KFA = shorter stride length = increased cadence), [12,13] as an adaptation to changing environmental conditions [28] and as an attenuator of vertical ground reaction forces. [39] In the current study, the C group showed no significant biomechanical changes in any of the 3 conditions. Furthermore, the PMRT training effect on the DO group not only produced a significant decrease in KFA and DFA in all 3 conditions and similarly on the DB group across all conditions except KFA_{OUT85} but it was also significantly greater than the C group. The net effect of PMRT on the KFA and DFA outcomes was likely a decrease in impact at landing and subsequent attenuation of

vertical ground reaction forces. [28,39] These changes are supported by the findings of Almeida et al, [81] a systematic review with meta-analysis addressing biomechanical differences in foot strike patterns during running, where an attenuation of VGRF and vertical loading rate occurs with increasing knee joint flexion at landing as well as decreasing dorsiflexion toward a more neutral ankle position. This in turn produces a shortened stride length and facilitates an increase in cadence to the desired minimum PMRT goal of 180 steps•min-^{1}. [12,81]

Cadence and Stride Length

The subjects performed all pre-tests at a self-selected stride frequency, which studies considered to be close to optimal in energy expenditure in experienced runners such as the participants. [82] We hypothesized an increase in cadence and a shortening of stride length. The PMRT cadence target after 6 weeks of instruction was a minimum of 180 steps•min^{-1}, or 90 steps•min^{-1} per leg [12]. At the onset of the study, the overall average cadence of the RFS runners for the submaximal treadmill test was 160 steps•min^{-1}, for the submaximal overground run was 166 steps•min^{-1}, and at maximal effort was 179 steps•min^{-1}. To produce a successful increase in cadence to separate MFS from RFS, the stride length needed to shorten through an increased knee flexion in the late swing phase to allow the landing foot to initiate contact closer to the body and permit a more rapid turnover [7,12].

Based on the KFA and DFA outcomes reported in previous studies, [13,27] we hypothesized that the DO and DB would experience increases in cadence in the three testing conditions. The DB group succeeded in significantly raising their mean cadence on the treadmill, as well as during the overground submaximal and maximal tests. The

DO group achieved a near significant increase on the treadmill, increasing to 174 steps•min^{-1}, a significant increase on the overground submaximal to 182 steps•min^{-1}. However, they showed no change in cadence at maximal effort, because they reached their cadence potential during the pre-test baseline maximal effort, running at a cadence of 188 steps•min^{-1}. In addition to the significant within-subject changes, the two intervention groups posted cadence increases that significantly separated them from the C group.

Stride lengths were only calculated for the two overground speed conditions. Studies examining stride length variations and running styles have reported stride length changes at higher speeds. [26,49] At the submaximal and maximal level the expected significant changes did not occur. The outcomes did not reflect a relationship with the changes in KFA. Given the substantial decreases in KFA evidenced in the treatment groups, a concurrent decrease in stride length was expected, but did not occur. A change in the original overground testing venue from a measured track to a pavement surface and the sporadic performance of the instrumented insoles created limitations in the stride length assessments, potentially under-reporting actual changes.

Conclusions

Based on biomechanics outcomes supporting an MFS landing style, the participant RFS runners effectively changed from landing on the heels to landing on the ball of the foot using PMRT over 6 weeks, partially meeting the study objective. When observing if using the EZRB made a kinematic difference, there was no significant biomechanical evidence separating the group using it and the group not using it. When observing muscle activations and cardiovascular changes, patterns differed between the

groups. Our results indicated runners training using drills only demonstrated more changes in the submaximal overground condition, including an improvement in performance, but at a greater cost, while runners training with the EZRB demonstrated more changes in the treadmill and overground maximal effort conditions, no improvement in performance, at no additional cost. Thus, while the effectiveness of the belt could not be established, the results warrant further investigation.

REFERENCES

1. Dicharry J. Kinematics and kinetics of gait: From lab to clinic. *Clin Sports Med*. 2010;29(3):347-364.

2. Nelson RC, Gregor RJ. Biomechanics of distance running: A longitudinal study. *Res Q*. 1976;47(3):417-428.

3. James SL, Bates BT, Osternig LR. Injuries to runners. *Am J Sports Med*. 1978;6(2):40-50.

4. Mann R, Hagy J. Biomechanics of walking, running, and sprinting. *Am J Sports Med*. 1980;8(5):345; 345-350; 350.

5. James SL, Jones DC. Biomechanical aspects of distance running injuries. In: Cavanagh PR, ed. *Biomechanics of distance running.* I ed. Champaign, IL : Human Kinetics Books,; 1990:249-269.

6. Daoud AI, Geissler GJ, Wang F, Saretsky J, Daoud YA, Lieberman DE. Foot strike and injury rates in endurance runners: A retrospective study. *Med Sci Sports Exerc*. 2012;44(7):1325-1334.

7. Goss DL, Gross MT. A review of mechanics and injury trends among various running styles. *US Army Med Dep J*. 2012:62-71.

8. Lieberman DE, Venkadesan M, Werbel WA, et al. Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature*. 2010;463(7280):531-535.

9. McGinnis P. *Biomechanics of sports and exercise, 3rd edition.* ; 2013.

10. Nicola TL, Jewison DJ. The anatomy and biomechanics of running. *Clin Sports Med*. 2012;31(2):187-201.

11. Perl DP, Daoud AI, Lieberman DE. Effects of footwear and strike type on running economy. *Med Sci Sports Exerc*. 2012;44(7):1335-1343.

12. Romanov N. *Dr. Nicholas Romanov's pose method of running.* 1st ed. ; 2004.

13. Arendse RE, Nokes TD, Azevedo LB, Romanov N, Schwellnus MP, Fletcher G. Reduced eccentric loading of the knee with the pose running method. *Med Sci Sports Exerc*. 2004;36(2):272-277.

14. Dallam GM, Wilber RL, Jadelis K, Fletcher G, Romanov N. Effect of a global alteration of running technique on kinematics and economy. *J Sports Sci*. 2005;23(7):757-764.

15. Romanov N, Fletcher G. Runners do not push off the ground but fall forwards via a gravitational torque. *Sports Biomech*. 2007;6(3):434-452.

16. Bobbert MF, Schamhardt HC, Nigg BM. Calculation of vertical ground reaction force estimates during running from positional data. *J Biomech*. 1991;24(12):1095-1105.

17. Cavanagh PR, Lafortune MA. Ground reaction forces in distance running. *J Biomech*. 1980;13(5):397-406.

18. De Lisa JA. *Gait analysis in the science of rehabilitation... rehabilitation research & development SVC...* Scientific and Technical Information Section, Baltimore, Md: United States Department of Veteran Affairs; 1999.

19. Munro CF, Miller DI, Fuglevand AJ. Ground reaction forces in running: A reexamination. *J Biomech*. 1987;20(2):147-155.

20. Wakeling JM, Von Tscharner V, Nigg BM, Stergiou P. Muscle activity in the leg is tuned in response to ground reaction forces. *J Appl Physiol*. 2001;91(3):1307-1317.

21. Zadpoor AA, Nikooyan AA. The relationship between lower-extremity stress fractures and the ground reaction force: A systematic review. *Clin Biomech (Bristol, Avon)*. 2011;26(1):23-28.

22. Kulmala JP, Avela J, Pasanen K, Parkkari J. Forefoot strikers exhibit lower running-induced knee loading than rearfoot strikers. *Med Sci Sports Exerc*. 2013.

23. Novacheck TF. The biomechanics of running. *Gait Posture*. 1998;7(1):77-95.

24. Ardigo LP, Lafortuna C, Minetti AE, Mognoni P, Saibene F. Metabolic and mechanical aspects of foot landing type, forefoot and rearfoot strike, in human running. *Acta Physiol Scand*. 1995;155(1):17-22.

25. Schubert A, Kempf J, Heiderscheit BC. Influence of stride frequency and length on running mechanics: A systematic review. *Sports Health*. 2014;6(3):210.

26. Mann R, Malisoux L, Nührenbörger C, Urhausen A, Meijer K, Theisen D. Association of previous injury and speed with running style and stride-to-stride fluctuations. *Scand J Med Sci Sports*. 2015;25(6):e638-e645.

27. Sol C, Mitchell K. Impact forces at the knee joint - A comparative study on running styles. *Med Sci Sports Exerc*. 2002;33(5):s128.

28. Derrick TR. The effects of knee contact angle on impact forces and accelerations. *Med Sci Sports Exerc*. 2004;36(5):832-837.

29. Elvin NG, Elvin AA, Arnoczky SP, Torry MR. The correlation of segment accelerations and impact forces with knee angle in jump landing. *J Appl Biomech*. 2007;23(3):203-212.

30. Irmischer BS, Harris C, Pfeiffer RP, DeBeliso MA, Adams KJ, Shea KG. Effects of a knee ligament injury prevention exercise program on impact forces in women. *J Strength Cond Res*. 2004;18(4):703-707.

31. Dufek JS, Bates BT. The evaluation and prediction of impact forces during landings. *Med Sci Sports Exerc*. 1990;22(3):370-377.

32. Puddle DL, Maulder PS. Ground reaction forces and loading rates associated with parkour and traditional drop landing techniques. *Journal of sports science & medicine*. 2013;12:122.

33. Crossley K, Bennell KL, Wrigley T, Oakes BW. Ground reaction forces, bone characteristics, and tibial stress fracture in male runners. *Med Sci Sports Exerc*. 1999;31(8):1088; 1088-1093; 1093.

34. Hreljac A. Impact and overuse injuries in runners. *Med Sci Sports Exerc*. 2004;36(5):845-849.

35. Hobara H, Sato T, Sakaguchi M, Sato T, Nakazawa K. Step frequency and lower extremity loading during running. *Int J Sports Med*. 2012;33(4):310-313.

36. Chumanov ES, Wille CM, Michalski MP, Heiderscheit BC. Changes in muscle activation patterns when running step rate is increased. *Gait Posture*. 2012;36(2):231-235.

37. Heiderscheit BC, Chumanov ES, Michalski MP, Wille CM, Ryan MB. Effects of step rate manipulation on joint mechanics during running. *Med Sci Sports Exerc*. 2011;43(2):296-302.

38. Farley CT, Gonzalez O. Leg stiffness and stride frequency in human running. *J Biomech*. 1996;29(2):181-186.

39. Derrick TR, Hamill J, Caldwell GE. Energy absorption of impacts during running at various stride lengths. *Med Sci Sports Exerc*. 1998;30(1):128-135.

40. Chapman RF, Laymon AS, Wilhite DP, McKenzie JM, Tanner DA, Stager JM. Ground contact time as an indicator of metabolic cost in elite distance runners. *Med Sci Sports Exerc*. 2012;44(5):917-925.

41. Tartaruga MP, Brisswalter J, Peyre-Tartaruga LA, et al. The relationship between running economy and biomechanical variables in distance runners. *Res Q Exerc Sport*. 2012;83(3):367-375.

42. Saunders PU, Telford RD, Pyne DB, et al. Short-term plyometric training improves running economy in highly trained middle and long distance runners. *J Strength Cond Res*. 2006;20(4):947-954.

43. Noakes TD. *The lore of running.* 4th ed. Champagne, IL: Human Kinetics; 2002.

44. Morgan DW, Bransford DR, Costill DL, Daniels JT, Howley ET, Krahenbuhl GS. Variation in the aerobic demand of running among trained and untrained subjects. *Med Sci Sports Exerc*. 1995;27(3):404-409.

45. Conley DL, Krahenbuhl GS. Running economy and distance running performance of highly trained athletes. *Med Sci Sports Exerc*. 1980;12(5):357-360.

46. Anderson T. Biomechanics and running economy. *Sports Med*. 1996;22(2):76-89.

47. Williams KR, Cavanagh PR. Relationship between distance running mechanics, running economy, and performance. *J Appl Physiol*. 1987;63(3):1236-1245.

48. Cavanagh PR, Williams KR. The effect of stride length variation on oxygen uptake during distance running. *Med Sci Sports Exerc*. 1982;14(1):30-35.

49. Ogueta-Alday A, Rodríguez-Marroyo JA, García-López J. Rearfoot striking runners are more economical than midfoot strikers. *Medicine & science in sports & exercise*. 2014;46(3):580-585.

50. Santos-Concejero J, Tam N, Granados C, et al. Interaction effects of stride angle and strike pattern on running economy. *International journal of sports medicine*. 2014;35(13):1118-1123.

51. Dumke CL, Pfaffenroth CM, McBride JM, McCauley GO. Relationship between muscle strength, power and stiffness and running economy in trained male runners. *International journal of sports physiology and performance*. 2010;5(2):249-261.

52. Cappellini G, Ivanenko YP, Poppele RE, Lacquaniti F. Motor patterns in human walking and running. *J Neurophysiol*. 2006;95(6):3426-3437.

53. Higashihara A, Ono. T, Kubota J, Okuwaki T, Fukubayashi T. Functional differences in the activity of the hamstring muscles with increasing running speed. *J Sports Sci*. 2010;28(10):1085-1092.

54. Jeffreys I. Motor learning-applications for agility. *Strength and conditioning journal*. 2006;28(5):72.

55. Faul F. Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior research methods*. 2009;41(4):1149-1160.

56. Damsted C, Nielsen RO, Larsen LH. Reliability of video-based quantification of the knee- and hip angle at foot strike during running. *International journal of sports physical therapy*. 2015;10(2):147-154.

57. Ahn AN, Brayton C, Bhatia T, Martin P. Muscle activity and kinematics of forefoot and rearfoot strike runners. *Journal of Sport and Health Science*. 2014;3(2):102-112.

58. Criswell EdD E, ed. *Cram's introduction to surface electromyography, second edition.* Sudbury, Ma: Jones and Bartlett Publishers; 2011.

59. Gobbo M, Maffiuletti NA, Orizio C, Minetto MA. Muscle motor point identification is essential for optimizing neuromuscular electrical stimulation use. *Journal of NeuroEngineering and Rehabilitation*. 2014;11(17).

60. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of electromyography and kinesiology*. 2000;10(5):361-374.

61. Contreras B, Vigotsky AD, Schoenfeld BJ, Beardsley C, Cronin J. A comparison of two gluteus maximus EMG maximum voluntary isometric contraction positions. 2015;3(e1261):2016.

62. de Ruiter, CJ, Hoddenbach JG, Huurnink A, de Haan A. Relative torque contribution of vastus medialis muscle at different knee angles. *Acta physiologica*. 2008;194(3):223-237.

63. Riemann BL, Limbaugh GK, Eitner JD, LeFavi RG. Medial and lateral gastrocnemius activation differences during heel-raise exercise with three different foot positions. *Journal of strength and conditioning research*. 2011;25(3):634-639.

64. Romanov N. *Dr. Nicholas Romanov's pose method of running companion drill book - video I.* Coral Gables, FL: Pose Tech Press; 2002.

65. Messier SP, Cirillo KJ. Effects of a verbal and visual feedback system on running technique, perceived exertion and running economy in female novice runners. *J Sports Sci*. 1989;7(2):113-126.

66. Daniels J, Krahenbuhl G, Foster C, Gilbert J, Daniels S. Aerobic responses of female distance runners to submaximal and maximal exercise. *Ann N Y Acad Sci*. 1977;301:726-733.

67. Astrand P.O. RK. *Textbook of work physiology.* New York: McGraw-Hill; 1987.

68. Wasserman K, Whipp BJ, Koyl SN, Beaver WL. Anaerobic threshold and respiratory gas exchange during exercise. *J Appl Physiol*. 1973;35(2):236-243.

69. Kyröläinen H, Komi PV, Belli A. Mechanical efficiency in athletes during running. *Scandinavian journal of medicine & science in sports*. 1995;5(4):200-208.

70. Yong JR, Silder A, Delp SL. Differences in muscle activity between natural forefoot and rearfoot strikers during running. *Journal of biomechanics*. 2014;47(15):3593-3597.

71. Shih Y, Lin K, Shiang T. Is the foot striking pattern more important than barefoot or shod conditions in running? *Gait Posture*. 2013;38(3):490-494.

72. Olin ED, Gutierrez GM. EMG and tibial shock upon the first attempt at barefoot running. *Human movement science*. 2013;32(2):343-352.

73. Montgomery G, Abt G, Dobson C, Smith T, Ditroilo M. Tibial impacts and muscle activation during walking, jogging and running when performed overground, and on motorised and non-motorised treadmills. *Gait & posture*. 2016;49:120-126.

74. Wank V, Frick U, Schmidtbleicher D. Kinematics and electromyography of lower limb muscles in overground and treadmill running. *International journal of sports medicine*. 1998;19(7):455-461.

75. Williams DS, McClay S, Manal KT. Lower extremity mechanics in runners with a converted forefoot strike pattern. *Journal of Applied Biomechanics*. 2000;16(2):210.

76. Nunns M, House C, Fallowfield J, Allsopp A, Dixon SJ. Biomechanical characteristics of barefoot footstrike modalities. *J Biomech*. 2013;46(15):2603-2610.

77. Gazendam M, Hof A. Averaged EMG profiles in jogging and running at different speeds. *Gait Posture*. 2007;25(4):604-614.

78. Hamner SR, Seth A, Delp SL. Muscle contributions to propulsion and support during running. *Journal of biomechanics*. 2010;43(14):2709-2716.

79. Kyröläinen H, Avela J, Komi PV. Changes in muscle activity with increasing running speed. *Journal of sports sciences*. 2005;23(10):1101-1109.

80. Riley PO, Dicharry J, Franz J, Croce UD, Wilder RP, Kerrigan DC. A kinematics and kinetic comparison of overground and treadmill running. *Medicine & Science in Sports & Exercise*. 2008;40(6):1093-1100.

81. Almeida MO, Davis IS, Lopes AD. Biomechanical differences of foot-strike patterns during running: A systematic review with meta-analysis. *Journal of Orthopedic Sports Physical Therapy*. 2015;45(10):738.

82. de Ruiter CJ, Verdijk PW, Werker W, Zuidema MJ, de Haan A. Stride frequency in relation to oxygen consumption in experienced and novice runners. *Eur J Sport Sci*. 2013.

83. Di Michele R, Merni F. The concurrent effects of strike pattern and ground-contact time on running economy. *Journal of science and medicine in sport /*. 2014;17(4):414-418.

FIGURES

Figure 1.1 Foot Strike Patterns

A) RFS and resultant VGRF **B) MFS and resultant VGRF**

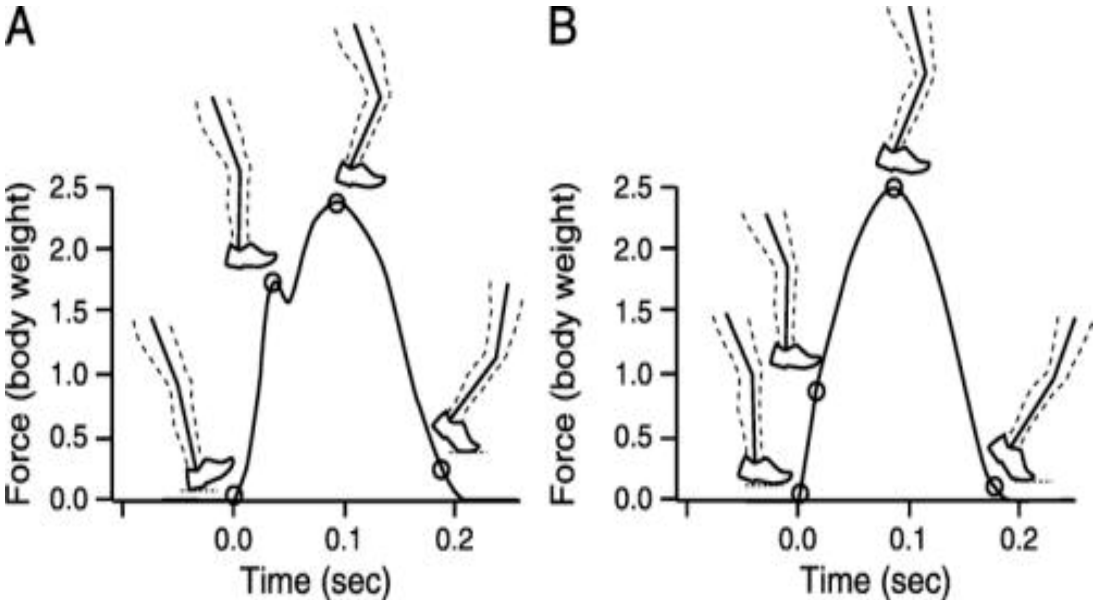


Figure 1.2 EZ Run Belt

A) EZ Run Belt components

B) EZ Run Belt with proper leg positioning

Figure 2.1 Experimental Protocol Flow Diagram

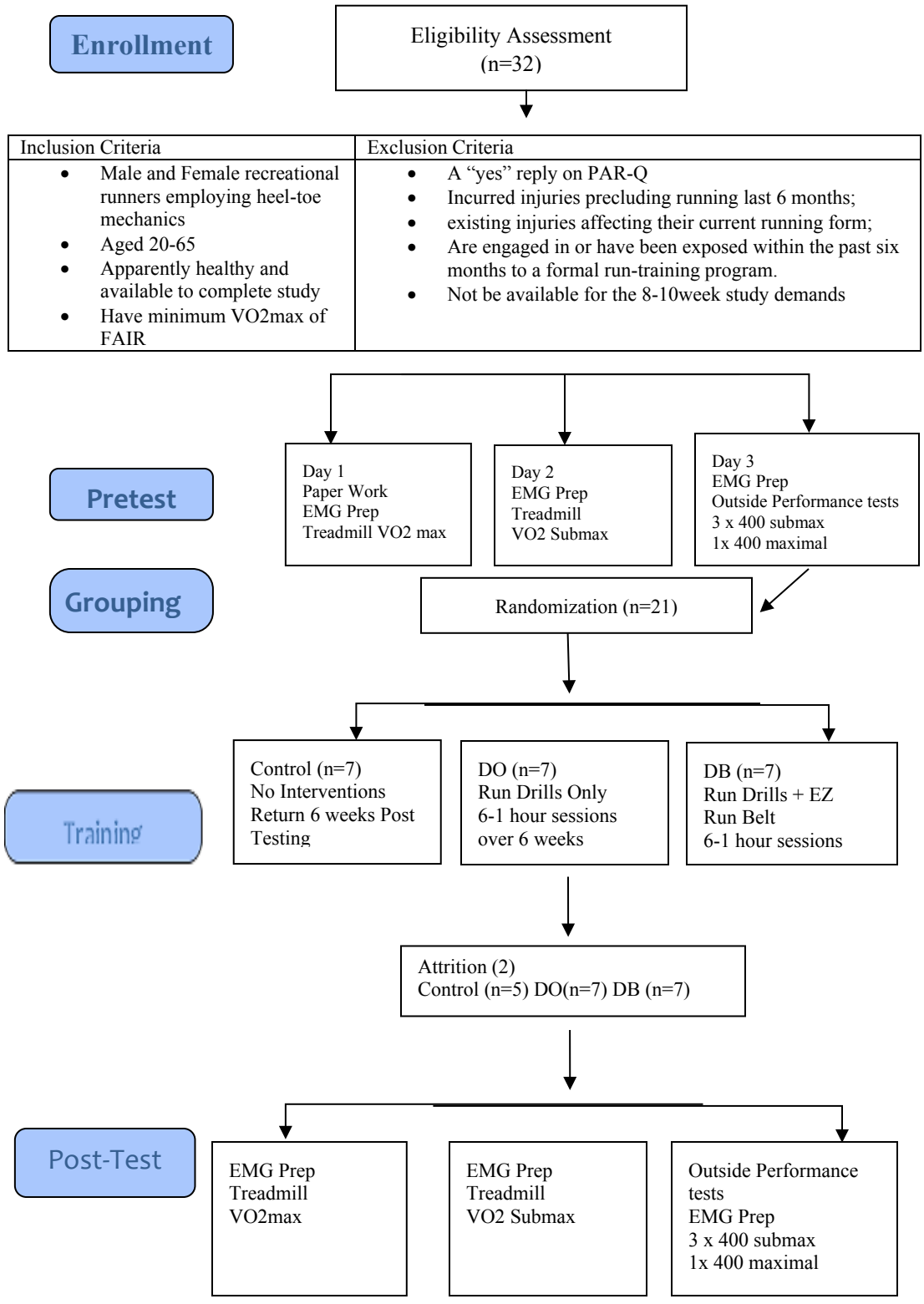
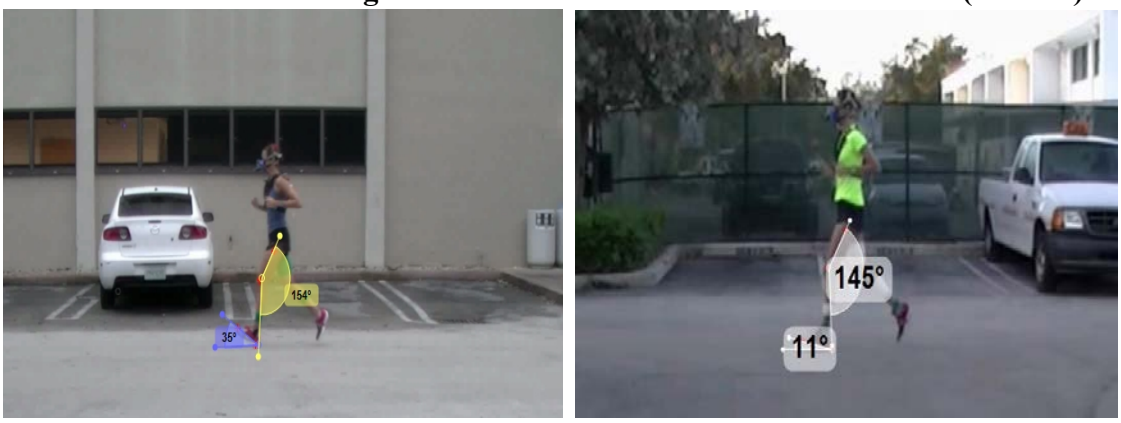


Figure 2.2 Pre and Post DO Runner Images

A. Pre and Post Treadmill 85% Lactate Threshold Heart Rate (TM85)

B. Pre and Post Overground 85% Lactate Threshold Heart Rate (OUT85)



C. Pre and Post Overground Maximal Effort (OUTMAX)

TABLES

TABLE 2.0 Subject demographics by group

GROUPS	CONTROL (C) (n=5)	DRILLS ONLY (DO) (n=7)	DRILLS+BELT (DB) (n=7)
Sex	M=4, F=1	M=3, F=4	M=6, F=1
AGE (y)	51±5.5	48±9.6	47±12
HEIGHT (m)	1.78±0.1	1.70±0.1	1.79±0.1
WT (kg)	78.6±14	67.3±12	80±9.5
VO_{2MAX}($ml^{-1}\cdot kg^{-1}\cdot min^{-1}$)	40.4±4.7	42.3±6.9	39±5.2
HR_{MAX} ($beats\cdot min^{-1}$)	173±10	173±16	171±16
HR_{LT} ($beats\cdot min^{-1}$)	150.2±6	151±10	144±20

Results are Mean ± SD

Table 3.1. **Cardiovascular and Performance Variables**

Outcome Measures	Baseline (M±SE)	Post (Diff) (M±SE)	Treatment Effect from C M±SE (95% CI)	Adj *p*	Treatment Effect from DO M±SE(95% CI)	Adj *p*
VO_{2MAX}						
C (n=5)	40.4± 2.6	-1.84±2.2				
DO (n=7)	42.3± 2.2	.043±1.8	-3.8 ±4.6 (-16,8.4)	.805		
DB (n=7)	39.0± 2.2	.957±1.8	-1.4±4.6 (13.7,10.8)	.986	2.3±4.2 (-8.8, 13.5)	.926
HR_{MAX}						
C (n=5)	173.0± 6.5	1.2±2.7				
DO (n=7)	172.6±5.5	1.0±2.3	.629±7.4 (-18.9,20.2)	1.00		
DB (n=7)	171.3± 5.5	-2.3±2.3	5.2±7.4 (-14.4,24.8)	.867	4.6±6.7 (-13.3,22.5)	.879
HR_{LT}						
C (n=5)	150± 6.3	**6.4±2.7***				
DO (n=7)	151± 5.4	.86±4.4	4.7±6.8 (-13.5, 23)	.874		
DB (n=7)	144± 5.4	-3.9±2.2	16.5±6.8 (-1.8,34.7)	.086	11.7±6.3 (-4.9, 28.4)	.220
$COST_{TM75}$						
C (n=5)	.84±.06	-.09±.08				
DO (n=7)	.99±.05	.12±.07	.35±.11 (.07,.63)	**.013***		
DB (n=7)	1.00±.05	-.07±.07	-.18±.11 (-.46,1.0)	.313	.17±.09 (-.09,.43)	.291
$COST_{TM85}$						
C (n=5)	.90±.06	-.01±.06				
DO (n=7)	.98±.05	.11±.05	.19±.10 (-.09, .47)	.250		
DB (n=7)	.97±.05	-.03±.05	.06±.10 (-.22, .33)	1.00	-.14±.10 (-.39, .12)	.503
RER_{TM85}						
C (n=5)	.94±.02	.00±.03				
DO (n=7)	.85±.02	**.07±.02***	-.02±.04 (-.13, .10)	1.00		
DB (n=7)	.92±.02	-.01±.02	-.03±.04 (-.14, .09)	1.00	-.01±.04 (-.11,.09)	1.00
RER_{OUT85}						
C (n=4)	.89±.03	**.10±.03***				
DO (n=6)	.86±.03	-.01±.03	-.13±.05 (-.25, -.01)	**.039***		
DB (n=7)	.92±.03	.00±.03	-.06±.04 (-.18, .06)	.623	.07±.04 (-.04, .18)	.274
RER_{OUTMAX}						
C (n=4)	1.03±.06	**.10±.05***				
DO (n=6)	.98±.04	-.00±.04	-.15±.05(-.30, -.02)	**.025***		
DB (n=7)	1.07±.04	-.06±.04	-.12±.05 (-.16, .09)	.075	.03±.04 (-.09, .14)	1.00
TP_{OUT85}						
C (n=5)	167.6±10.8	1.8±8.8				
DO (n=7)	163.1± 9.1	-4.1±7.4	-10.4±8.7(-33.6,12.8)	.746		
DB (n=7)	166.4± 9.1	-1.7±7.4	-4.7±8.7(-27.9,18.5)	1.00	5.71±7.9(-15.5,26.9)	1.00
TP_{OUTMAX}						
C (n=5)	119.2± 9.3	7.4±2.8				
DO (n=7)	116.6± 7.9	**-6.6±2.4***	-16.6±12.1(-49, 15.8)	.570		
DB (n=7)	117.6± 7.9	-.143±2.4	-9.2±12.1(-41.6,23.2)	1.00	7.4±11.1(-22.2,37.0)	1.00

*significant difference from Pre-test, $p<.05$

Table 3.2. Normalized Electromyographic Measures for the Quadriceps Muscles

Outcome Variables	Baseline (M±SE)	Post (Diff) (M±SE)	Treatment Effect from C M±SE (95% CI)	Adj *P*	Treatment Effect from DO M±SE (95% CI)	Adj *p*
RF_{TM85}						
C (n= 5)	.0312±.005	-.007±.007				
DO (n=5)	.0337±..005	.004±.007	.013±.006 (-.002, .029)	.093		
DB (n=7)	.0266±..005	-.004±.006	-.001±.005 (-.015, .013)	1.00	-.014±.005(-.029,.000)	**.042***
RF_{OUT85}						
C (n=1)	.0251±. 020	.060±.024				
DO (n=5)	.0394± .009	**.026±.011***	-.020±.024 (-.093, .054)	1.00		
DB (n=4)	.0356± .010	-.001±.012	-.051±.024 (-.126, .025)	.223	-.031±.014(-.076,.014)	.208
RF_{OUTMAX}						
C (n=4)	.0451± .012	-.009±.017				
DO (n=6)	.0502±..010	.027±.013	.040±.020 (-.014, .095)	.187		
DB (n=5)	.0461±..011	-.001±.015	.009±.020 (-.048, .065)	1.00	-.032±.018(-.083,.019)	.331
VL_{TM85}						
C (n=4)	.0980±..012	.032±.024				
DO (n= 7)	.1115±..009	-.001±.018	-.019±.035 (-.115, .077)	1.00		
DB (n=7)	.0874±..009	.017±.018	-.025±.035 (-.121, .070)	1.00	-.006±.030(-.088,.075)	1.00
VL_{OUT85}						
C (n=4)	.1129±..022	.041±.023				
DO (n= 6)	.1266±..018	-.002±.019	-.30±.026 (-.100, .041)	.804		
DB (n=6)	.0877±..018	.016±.019	-.050±.026 (-.121, .020)	.214	-.021±.023(-.084,.042)	1.00
VL_{OUTMAX}						
C (n=4)	.1583±..044	.018±.026				
DO (n= 7)	.1947±..033	-.005±.019	.013±.039 (-.094, .121)	1.00		
DB (n=5)	.1080±..040	.012±.023	-.056±.042 (-.171, .059)	.243	-.069±.037(-.170,.031)	.243

*significant difference from Pre-test, $p<.05$

Table 3.3. Normalized Electromyographic Measures for the Hamstring Muscles

Outcome Variables	Baseline (M±SE)	Post (Diff) (M±SE)	Treatment Effect from C M±SE (95% CI)	Adj *P*	Treatment Effect from DO M±SE (95% CI)	Adj *P*
BF_{TM85}						
C (n=5)	.0311.± .010	.011±.006				
DO (n=7)	.0555± .008	.008±.005	.022±.012 (-.010, .054)	.246		
DB (n=7)	.0435± .008	**.016±.005***	.018±.011 (-.014, .050)	.447	-.004±.011 (-.033, .025)	1.00
BF_{OUT85}						
C (n=4)	.0439± .013	.005±.014				
DO(n=5)	.0582± .012	**.041±.013***	.050±.023 (-.015, .114)	.162		
DB (n=6)	.0435± .011	**.029±.012***	.023±.022 (-.039, .085)	.962	-.026±.021 (-.085, .032)	.693
BF_{OUTMAX}						
C(n=5)	.070± .010	.007±.015				
DO (n=7)	.0826± .009	.009±.012	.015±.023 (-.045, .075)	1.00		
DB (n=7)	.0521± .009	**.044±.012***	.019±.023 (-.041, .079)	1.00	.004±.021 (-.051, .059)	1.00
ST_{TM85}						
C (n=5)	.1113± .022	.020±.021				
DO (n=6)	.0618± .020	**.064±.019***	-.005±.028 (-.082, .071)	1.00		
DB (n=7)	.0603± .019	**.055±.018***	-.017±.028 (-.091, .057)	1.00	-.011±.026 (-.082, .059)	1.00
ST_{OUT85}						
C (n=3)	.098±..029	.028±.026				
DO (n=6)	.0863± .020	.035±.018	-.005±.032 (-.092, .083)	1.00		
DB (n=6)	.1183±..020	.027±.018	.019±.032 (-.068, .107)	1.00	.024±.06 (-.047, .096)	1.00
ST_{OUTMAX}						
C (n=4)	.1982± .040	-.036±.042				
DO (n=5)	.1501± .035	.010±.037	-.002±.047 (-.134, .130)	1.00		
DB (n=5)	.1251± .035	**.107±.037***	.070±.047 (-.062, .202)	.485	.073±.044 (-.052, .197)	.386

*significant difference from Pre-test, $p<.05$

Table 3.4. Normalized Electromyographic Measures for the Gastrocnemius

Outcome Variables	Baseline (M±SE)	Post (Diff) (M±SE)	Treatment Effect from C (M±SE 95% CI)	Adj *P*	Treatment Effect from DO (M±SE 95% CI)	Adj *P*
LG_{TM85}						
C (n=5)	.0570±.008	-.001±.008				
DO (n=7)	.0704±.007	-.007±.007	.007±.011 (-.021, .036)	1.00		
DB (n=7)	.0608±.007	-.003±.007	.002±.011 (-.027, .031)	1.00	-.005±.010 (-.032, .021)	1.00
LG_{OUT85}						
C (n=4)	.0686±.015	-.006±.015				
DO (n=5)	.0605±.013	**.030±.014***	.028±.022 (-.034, .090)	.708		
DB (n=6)	.0850±.012	.013±.012	.036±.021 (-.024, .095)	.368	.008±.020 (-.048, .064)	1.00
LG_{OUTMAX}						
C (n=5)	.0973±.014	.002±.014				
DO (n=7)	.0856±.012	.012±.012	-.002±.024 (-.067, .063)	1.00		
DB (n=7)	.1102±.012	-.005±.012	.006±.024 (-.059, .071)	1.00	.008±.022(-.051, .067)	1.00

*significant difference from Pre-test, $p<.05$

Table 3.5 Cadence and Stride Length Measures

Outcome Measures	Baseline (M±SE)	Post (Diff) (M±SE)	Treatment Effect from C M±SE (95% CI)	Adj *p*	Treatment Effect from DO M±SE (95% CI)	Adj *p*
CAD_{TM85}						
C (n=4)	77.8±2.0	-.50±1.9				
DO (n=7)	84.0±1.5	2.7±1.4	9.5±2.3 (3.3, 15.7)	**.003***		
DB (n=7)	79.9±1.5	**3.9±1.4***	6.5±2.3 (.3, 12.7)	**.039***	-3.0±2.0 (-8.3, 2.3)	.440
CAD_{OUT85}						
C (n=4)	82.2±2.7	1.2±2.3				
DO (n=6)	85.7±2.2	**4.7±1.8***	6.8±3.6 (-2.9, 16.6)	.230		
DB (n=6)	83.3±2.2	**5.0±1.8***	4.8±3.6 (-4.9, 14.6)	.590	-2.0±3.2 (-10.7,6.7)	1.00
CAD_{OUTMAX}						
C (n=5)	87.4±2.6	.20±.8				
DO (n=6)	93.2±2.4	.67±.7	6.2±3.2 (-2.3, 14.8)	.207		
DB (n=7)	89.3±2.2	**4.7±.7***	6.4±3.1 (-1.9, 14.7)	.165	.2±2.9 (-7.7, 8.0)	1.00
SL_{OUT85}						
C (n=4)	1.8±.1	-1.10±.1				
DO (n=6)	1.7±.1	-.02±.1	.01±.1 (-.24, .25)	1.00		
DB (n=6)	1.8±.1	-.10±.1	-.02±.1 (-.26, .23)	1.00	-.02±.1 (-.2, .2)	1.00
SL_{OUTMAX}						
C (n=5)	2.4±.1	**-.20±.1***				
DO (n=6)	2.2±.1	.10±.1	.10±.2 (-.48, .68)	.216		
DB (n=7)	2.3±.1	-.11±.1	-.03±.2 (-.59, .53)	.209	-.13±.2 (-.7, .4)	.198

*significant difference from Pre-test, $p<.05$

Table 3.6 Knee Flexion and Dorsiflexion Angles at Initial Landing Measures

Outcome Measures	Baseline (M±SE)	Post (Diff) (M±SE)	Treatment Effect from C M±SE (95% CI)	Adj *p*	Treatment Effect from DO M±SE (95% CI)	Adj *p*
KFA$_{TM85}$						
C (n=5)	163.8±1.8	-3.6±2.0				
DO (n=7)	163.4±1.5	**-5.4±1.7***	-2.2±3.6 (-12.0, 7.6)	1.00		
DB (n=5)	159.4±1.8	**-6.6±2.0***	-7.4±3.9 (-18.0, 3.2)	.237	-5.2±3.6 (-15.0, 4.6)	.517
KFA$_{OUT85}$						
C (n=4)	163.2±3.2	-1.0±1.5				
DO(n=5)	159.4±2.9	**-6.2±1.4***	-9.1±4.5 (-21.8, 3.7)	.214		
DB(n=5)	158.0±2.9	-2.3±1.8	-7.1±4.5 (-19.8, 5.7)	.445	2.0±4.3 (-10.1, 14.1)	1.00
KFA$_{OUTMAX}$						
C (n=5)	157.8±3.3	.8±1.9				
DO (n=5)	157.2±3.3	**-5.6±1.9***	-7.0±4.1 (-18.1, 4.1)	.330		
DB (n=7)	157.7±2.8	**-7.7±1.6***	-8.6±3.8 (-18.9, 1.7)	.120	-1.6±3.8 (-11.9, 8.7)	1.00
DFA $_{TM85}$						
C (n=5)	33.0±2.1	.8±2.4				
DO (n=7)	31.6±1.7	**-8.1±2.0***	-10.4±3.6 (-20.3, -.5)	**.039***		
DB (n=5)	31.6±2.1	**-9.6±2.4***	-11.8±3.9 (-22.5, -1.1)	**.029***	-1.4±3.6 (-11.3, 8.5)	1.00
DFA $_{OUT85}$						
C (n=4)	37.8±2.7	-1.5±2.6				
DO (n=5)	33.8±2.4	**-11.6±2.3***	-14.1±4.2 (-25.8, -2.3)	**.019***		
DB (n=5)	33.8±2.4	**-8.2±2.3***	-10.7±4.2 (-22.4, 1.1)	.080	3.4±3.9 (-7.7, 14.5)	1.00
DFA$_{OUTMAX}$						
C (n= 5)	36.6±2.2	-.6±3.5				
DO (n=5)	36.0±2.2	**-15.6±3.5***	-15.6±4.6 (-28.0, -3.2)	**.013***		
DB (n=7)	36.6±1.9	**-10.7±3.0***	-10.1±4.2 (-21.6, 1.3)	.093	5.5±4.2 (-6.0, 16.9)	.653

*significant difference from Pre-test, $p<.05$

APPENDIX A

TABLE OF ACRONYM DEFINITION

CONDITIONS	**ACRONYMS**	
Run on treadmill at 75% of HR_{LT}	TM75	
Run on treadmill at 85% of HR_{LT}	TM85	
Run 400 m on ground outside at 85% HR_{LT}	OUT85	
Run 400 m on ground maximal effort	OUTMAX	
VARIABLES		
BIOMETRIC		**UNITS**
Age	AGE	Years (y)
Height	HT	Meters (m)
Weight	WT	kg
Gender	GEN	
PHYSIOLOGICAL		
Vo2 Max	VO_{2MAX}	$ml^{-1} \bullet kg^{-1} \bullet min^{-1}$
Maximal Heart Rate	HR_{MAX}	$b \bullet min^{-1}$
Lactate Threshold Heart Rate	HR_{LT}	$b \bullet min^{-1}$
Performance Time x 400 m	TP	Sec (s)
Oxygen Cost	COST	$ml^{-1} \bullet kg^{-1} \bullet min^{-1}$
Respiratory Exchange Ratio	RER	
MUSCLE EMG		Millivolts
Rectus Femoris	RF	µV
Vastus Lateralis	VL	µV
Biceps Femoris	BF	µV
Semitendinosus	ST	µV
Lateral Gastrocnemius	LG	µV
BIOMECHANICAL		**UNITS**
Cadence	CAD	$steps \bullet min^{-1}$
Stride Length	SL	$meters \bullet step^{-1}$
Knee Flexion Angle at Initial Contact	KFA	DEG (°)
Ankle Dorsiflexion Angle at Initial Contact	DFA	DEG (°)

APPENDIX B

VO2MAX NORMATIVE TABLES

Normative data for Female (values in ml/kg/min)

Age	Poor	Fair	Good	Excellent	Superior
20 - 29	<36	36 - 39	40 – 43	44 - 49	>49
30 - 39	<34	34 - 36	37 – 40	41 - 45	>45
40 - 49	<32	32 - 34	35 – 38	39 - 44	>44
50 - 59	<25	25 - 28	29 – 30	31 - 34	>34
60 - 69	<26	26 - 28	29 – 31	32 - 35	>35
70 - 79	<24	24 - 26	27 – 29	30 - 35	>35

Normative data for Male (values in ml/kg/min)

Age	Poor	Fair	Good	Excellent	Superior
20 - 29	<42	42 - 45	46 – 50	51 - 55	>55
30 - 39	<41	41 - 43	44 – 47	48 - 53	>53
40 - 49	<38	38 - 41	42 – 45	46 - 52	>52
50 - 59	<35	35 - 37	38 – 42	43 - 49	>49
60 - 69	<31	31 – 34	35 – 38	39 - 45	>45
70 - 79	<28	28 – 30	31 – 35	36 - 41	>41

HEYWOOD, V. (2006) The Physical Fitness Specialist Manual, The Cooper Institute for Aerobics Research, Dallas TX, revised 2005. In: HEYWOOD, V (2006) *Advanced Fitness Assessment and Exercise Prescription*, Fifth Edition, Champaign, IL: Human Kinetics

APPENDIX C

CSEP approved Sept 12 2011 version

PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

Regular physical activity is fun and healthy, and more people should become more physically active every day of the week. Being more physically active is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

SECTION 1 - GENERAL HEALTH

	Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1.	Has your doctor ever said that you have a heart condition OR high blood pressure?	☐	☐
2.	Do you feel pain in your chest at rest, during your daily activities of living, OR when you do physical activity?	☐	☐
3.	Do you lose balance because of dizziness OR have you lost consciousness in the last 12 months? Please answer NO if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4.	Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)?	☐	☐
5.	Are you currently taking prescribed medications for a chronic medical condition?	☐	☐
6.	Do you have a bone or joint problem that could be made worse by becoming more physically active? Please answer NO if you had a joint problem in the past, but it does not limit your current ability to be physically active. For example, knee, ankle, shoulder or other.	☐	☐
7.	Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.

Go to Section 3 to sign the form. You do not need to complete Section 2.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow the Canadian Physical Activity Guidelines for your age (www.csep.ca/guidelines).
- You may take part in a health and fitness appraisal.
- If you have any further questions, contact a qualified exercise professional such as a CSEP Certified Exercise Physiologist® (CSEP-CEP) or CSEP Certified Personal Trainer® (CSEP-CPT).
- If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

If you answered YES to one or more of the questions above, please GO TO SECTION 2.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better
- You are pregnant – talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- Your health changes – please answer the questions on Section 2 of this document and/or talk to your doctor or qualified exercise professional (CSEP-CEP or CSEP-CPT) before continuing with any physical activity programme.

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SECTION 2 - CHRONIC MEDICAL CONDITIONS

Please read the questions below carefully and answer each one honestly: check YES or NO.			YES	NO
1.	Do you have Arthritis, Osteoporosis, or Back Problems?		☐ If yes, answer questions 1a-1c	☐ If no, go to question 2
	1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	☐	☐
	1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/ or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	☐	☐
	1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	☐	☐
2.	Do you have Cancer of any kind?		☐ If yes, answer questions 2a-2b	☐ If no, go to question 3
	2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and neck?	☐	☐
	2b.	Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?	☐	☐
3.	Do you have Heart Disease or Cardiovascular Disease? This includes Coronary Artery Disease, High Blood Pressure, Heart Failure, Diagnosed Abnormality of Heart Rhythm		☐ If yes, answer questions 3a-3e	☐ If no, go to question 4
	3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	☐	☐
	3b.	Do you have an irregular heart beat that requires medical management? (e.g. atrial brillation, premature ventricular contraction)	☐	☐
	3c.	Do you have chronic heart failure?	☐	☐
	3d.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer YES if you do not know your resting blood pressure)	☐	☐
	3e.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	☐	☐
4.	Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes		☐ If yes, answer questions 4a-4c	☐ If no, go to question 5
	4a.	Is your blood sugar often above 13.0 mmol/L? (Answer YES if you are not sure)	☐	☐
	4b.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, and the sensation in your toes and feet?	☐	☐
	4c.	Do you have other metabolic conditions (such as thyroid disorders, pregnancy-related diabetes, chronic kidney disease, liver problems)?	☐	☐
5.	Do you have any Mental Health Problems or Learning Difficulties? This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome)		☐ If yes, answer questions 5a-5b	☐ If no, go to question 6
	5a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	☐	☐
	5b.	Do you also have back problems affecting nerves or muscles?	☐	☐

Please read the questions below carefully and answer each one honestly: check YES or NO.			YES	NO
6.	Do you have a Respiratory Disease? This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure		☐ If yes, answer questions 6a-6d	☐ If no, go to question 7
	6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	☐	☐
	6b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	☐	☐
	6c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	☐	☐
	6d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	☐	☐
7.	Do you have a Spinal Cord Injury? This includes Tetraplegia and Paraplegia		☐ If yes, answer questions 7a-7c	☐ If no, go to question 8
	7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	☐	☐
	7b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	☐	☐
	7c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	☐	☐
8.	Have you had a Stroke? This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event		☐ If yes, answer questions 8a-c	☐ If no, go to question 9
	8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	☐	☐
	8b.	Do you have any impairment in walking or mobility?	☐	☐
	8c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	☐	☐
9.	Do you have any other medical condition not listed above or do you live with two chronic conditions?		☐ If yes, answer questions 9a-c	☐ If no, read the advice on page 4
	9a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months OR have you had a diagnosed concussion within the last 12 months?	☐	☐
	9b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	☐	☐
	9c.	Do you currently live with two chronic conditions?	☐	☐

Please proceed to Page 4 for recommendations for your current medical condition and sign this document.

PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active:

- It is advised that you consult a qualified exercise professional (e.g., a CSEP-CEP or CSEP-CPT) to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually – 20-60 min. of low- to moderate-intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate-intensity physical activity per week.
- If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

If you answered YES to one or more of the follow-up questions about your medical condition:

- You should seek further information from a licensed health care professional before becoming more physically active or engaging in a fitness appraisal and/or visit a or qualified exercise professional (CSEP-CEP) for further information.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise profesional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- Your health changes - please talk to your doctor or qualified exercise professional (CSEP-CEP) before continuing with any physical activity programme.

SECTION 3 - DECLARATION

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The Canadian Society for Exercise Physiology, the PAR-Q+ Collaboration, and their agents assume no liability for persons who undertake physical activity. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.
- Please read and sign the declaration below:

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that they maintain the privacy of the information and do not misuse or wrongfully disclose such information.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

For more information, please contact:
Canadian Society for Exercise Physiology
www.csep.ca

KEY REFERENCES
1. Jamnik VJ, Warburton DER, Makarski J, McKenzie DC, Shephard RJ, Stone J, and Gledhill N. Enhancing the eectiveness of clearance for physical activity participation; background and overall process. APNM 36(S1):S3-S13, 2011.
2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-s298, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or BC Ministry of Health Services.

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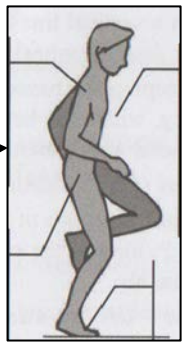
APPENDIX D

POSE METHOD OF RUNNING TECHNIQUE DRILLS

POSE – FALL - PULL ARE THE POSE METHOD BASIC COMPONENTS

DRILL PROGRESSION FOLLOWED THAT SEQUENCE

BALANCE DRILLS (POSE POSITION PROPIOCEPTION)



1) POSE STANCE (RUNNING POSE)
   - Shoulders, hips and ankle on vertical line of support
   - Body slightly leaning forward
   - S-stance on two legs with knees slightly bent, then standing on one leg
   - Body weight on ball of the foot (BOF), heel touches ground lightly without any weight
2) BOUNCING
   - Basis of all drills
   - Objective: balance, work with VGRF, muscle rebound
3) CHANGE IN SUPPORT
   - Objective: balance, support on BOF, S-stance
4) SINGLE LEG HOP IN PLACE
   - Objective: balance, pull ankle under body, support BOF, cadence
5) TOES UP
   - Objective: balance, changing support, coordination, ankle strength
6) FORWARD LUNGE
   - Objective: balance, support BOF, coordination, pull ankle up
7) SINGLE SKIP
   - Objective: balance, muscle rebound (bouncing), coordination, pull ankle up
8) HAND TO FOOT
   - Objective: balance, coordination, changing support, muscle rebound
9) BASE JUMP IN PLACE
   - Objective: balance, coordination, support BOF, pulling, strength

10) HEEL TOUCH
    - Objective: balance, coordination, strength, hamstring activation

FALL DRILLS (BALANCE DESTRUCTION, WORK WITH GRAVITY)

11) FALL TOWARDS PARTNER FROM TWO FEET
    - Objective: Falling concept (not bending)

12) FALL TOWARDS PARTNER FROM POSE POSITION
    - Objective: Falling concept

13) FALL FORWARD WITH CHANGE SUPPORT
    - Objective: Falling, changing support, coordination, pulling – not landing

14) FALL TO THE SIDE FROM POSE POSITION
    - Objective: Falling, pulling leg from support, coordination

PULL (FORWARD MOVEMENT, GRAVITY, HAMSTRINGS, COORDINATION)

These drills just teach continuous forward movement to Balance and Fall Drills incorporating the chain Pose – Fall – Pull, and engaging the hamstrings by encouraging increased knee flexion

15) FORWARD TOES UP
16) FORWARD SINGLE LEG HOP
17) FORWARD LUNGE
18) FORWARD SINGLE SKIP
19) FORWARD HAND TO FOOT
20) FORWARD HEEL TOUCH