DEFICITS IN FUNCTIONAL MOVEMENT PATTERNS AND RUNNING ECONOMY OF TRAINED ENDURANCE RUNNERS

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ABSTRACT

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INTRODUCTION: It has been well established that the mechanics of running gait play a significant role in running economy. Running gait is influenced by many musculoskeletal factors, which can change movement patterns. An individual's fundamental dynamic movement patterns can be evaluated using the Functional Movement Screen (FMS). Individuals with less movement deficits, specifically asymmetries, may demand less oxygen during activity than individuals with more movement deficits.

PURPOSE: This study looked at how deficits in functional movement patterns relate to the running economy of trained endurance runners. Specifically, one aim of this study was to demonstrate that runners who have one or more asymmetries during the FMS demand more oxygen as they run. A second aim was to demonstrate that runners who score 14 or less on the FMS demand more oxygen. A third aim was to demonstrate that runners who score a 2 or less on the Hurdle Step test demand more oxygen than runners who score a 3 on the Hurdle Step FMS test.

METHODS: Forty trained endurance runners were tested in the lab on one occasion. Each subject performed all 7 movement tests of the FMS. Next, each subject performed a running economy test consisting of 3 4-minute submaximal trials on the treadmill (women: 10, 12, and 14 km/hr; men: 12, 14, and 16 km/hr). An independent t-test was utilized for each independent variable of interest (asymmetry presence, total FMS score, Hurdle Step score). An alpha of $p<0.05$ was used to indicate statistical significance.

RESULTS: There was a significant difference in running economy between the asymmetrical group (n=21) and the symmetrical group (n=19), only at the speed of 14 km/hour. Contrary to our original hypothesis, the asymmetrical group was more economical than the symmetrical group. Comparing running economy between asymmetrical and symmetrical FMS scorers (men and women together and separately) at all other speeds did not reach statistical significance. There was no difference between running economy of the FMS Hurdle Step test score of 3 group (n=19) and the FMS Hurdle Step test score of 2 or less group (n=21) at any speed. Furthermore, there was no difference between running economy of the FMS Total Score of 14 or less group (n=2) and the FMS Total Score of 15 or more group (n=38) at any speed.

CONCLUSION: Trained runners who displayed movement asymmetries as determined by the Functional Movement Screen demonstrated lower oxygen uptakes during submaximal running than runners who were symmetrical on the FMS movements. Although movement asymmetries have been linked to higher injury risk, there may be an advantage of lower metabolic cost during running, which may be due to differences in leg stiffness. Although total FMS score and scores specifically on the hurdle step movement did not influence running economy, the FMS screen remains a staple of pre-participation screening for athletes of all disciplines.

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CHAPTER 1: INTRODUCTION

Performance in endurance running is influenced by many physiological factors including lactate threshold, VO_2 max, and running economy. The energy cost of movement at a given pace, defined as the term running economy, plays a key role in running ability (Morgan 1989). Those who consume less oxygen while running at a steady state at a given pace are said to have a better running economy (Cavanagh 1987). It has been suggested that of all physiological variables, running economy explains the largest portion of the variance in endurance exercise performance between individuals (Morgan 1989). There are many factors that influence running economy including age, gender, environment, and training (Saunders 2004). It has been well established that the mechanics of running gait also play a significant role in running economy (Cavanagh 1987), though the specific musculoskeletal and neural factors that directly influence running gait patterns have yet to be distinguished.

A clinical analysis of movement quality includes body symmetry, an important objective measurement examined by physical therapists (Cronin 2013). Asymmetries are caused by movement dysfunctions, which are caused by underlying mobility and/or stability issues (Cook 2010). Asymmetries in movement patterns can lead to compensations elsewhere in the body and may increase the risk of injury (Cook 2010). While completing simple measures of strength and flexibility of an athlete are informative, these measures do not reflect natural movement patterns and tell little about how that athlete actually moves as they perform (Cook 2010). Asymmetries may seem minor during a movement test, such as a lunge, but may play a larger role if they cause biomechanical changes during dynamic movements such as running. Assessing movement patterns and asymmetries that influence gait with a simple assessment, such as the Functional Movement Screen, may offer a means by which to investigate mechanisms behind poor gait mechanics leading to poor running economy in endurance runners.

The Functional Movement Screen (FMS) is a tool to assess movement patterns basic to the normal function of active people (Cook 2010). Running is a highly complex dynamic movement that uses the entire body, making it an appropriate activity to relate to FMS results. There are 7 FMS tests (Deep Squat, Hurdle Step, In-Line Lunge, Shoulder Mobility, Active Straight Leg Raise, Trunk Stability Push-up, and Rotational Stability) that examine balance, proprioception, strength, flexibility, coordination, and range of motion (Cook, Burton et al. 2006). Five of the seven tests are done bilaterally, with a score given for each side. Thus, the FMS can be used to detect movement asymmetries. The FMS tests are graded on a 0-3 point whole number scale; with a total possible score of 21 (Cook 2010). FMS performance has also been linked to injury prediction. Numerous studies have named a total score of 14 as the cut-off score for injury prevalence, and equal to or lower than that score implies greater injury risk (Kiesel, Plisky et al. 2007). Further, Chapman et al. found that elite track and field athletes with FMS scores of 14 or less showed a difference in longitudinal competitive performance outcomes from those with an FMS score of 15 or higher, with an overall decrease in performance (Chapman, Laymon et al. 2014). If dysfunction is found during the FMS, it stands to reason that the same natural dysfunctional movement pattern will likely exist as the individual runs.

The purpose of this study was to determine how functional movement deficits and asymmetries relate to running economy of an endurance runner. Assuming the dysfunctions found in the FMS translate to running, the subject would compensate their gait, increasing oxygen demand, causing them to be less economical and negatively affecting their running abilities and performance. It was hypothesized that runners with one or more asymmetries will have poorer running economy than runners with no asymmetries due to compensatory running mechanics. It was also hypothesized that runners who score 14 or less overall on the FMS will have poorer running economy than runners with an overall FMS score of 15 or higher. Finally, it was hypothesized that runners who score 2 or less on the Hurdle Step test will have poorer running economy than runners who score a 3 on the Hurdle Step. This test was analyzed individually because it mimics stride mechanics during a stepping motion (Cook 2010). The Hurdle Step test involved major contributions from the gluteus maximum, iliopsoas, and hamstrings, which are also major muscles involved in running. Therefore, performance on the Hurdle Step test is relatable to running mechanics.

Statement of the Problem

Running economy is a valuable tool for evaluating and understanding the oxygen cost of running of an endurance runner. Functional movement deficits, specifically asymmetries, may impact running economy performance. Though previous studies established that body mechanics and gait patterns can impact running economy outcome, no published research has investigated the effect of functional movement asymmetries on running economy in endurance runners. Because of the common occurrence of musculoskeletal injuries, it is important to understand how underlying causes of injury may affect performance, even before injury.

Purpose of the Study

The purpose of this study was to evaluate how deficits in functional movement patterns relate to the running economy of endurance runners.

Delimitations

1. Healthy, trained male and female endurance runners were recruited as volunteer subjects for this study.
2. Subjects were recruited from the Indiana University campus via flyers, contact with the Indiana Running Club, and from the Indiana Track and Field team.
3. Data collection occurred in a laboratory setting where temperature, humidity and barometric pressure are relatively static.
4. Subjects were asked to wear comfortable clothing that allowed mobility and athletic shoes.
5. Subjects were asked not to exercise within 12 hours of testing.
6. Subjects were asked to arrive for testing at least 3 hours post-prandial, and to be properly hydrated.
7. Subjects were considered asymmetrical if their raw scores for the Hurdle Step, In-line Lunge, Active Straight Leg Raise, Shoulder Mobility, or Rotary Stability were different for left and right side of their body.

Limitations

1. The subjects were selected for the study based on running history, and subject data was included based on VO_2max values.
2. Subjects were asked to refrain from exercise 12 hours prior to testing, but it is not possible to know if this was done.

3. Subjects filled out a health questionnaire that addressed any pre or existing health conditions before any testing was conducted, but it is impossible to know the degree of their honesty.
4. Subjects were asked to end on the treadmill with a VO_2max running test, and perform to their fullest ability. Unfortunately, there is no way to know if the subjects performed to the best of their ability.

Assumptions

1. Subjects did not participate in exercise within 12 hours of testing.
2. Subjects arrived at least 3 hours post-prandial and were properly hydrated.
3. Subjects were highly motivated to complete the Functional Movement Screen and VO_2max running test with the highest level of performance.
4. Subjects did not change their natural running mechanics while being tested on a unique treadmill.
5. The Functional Movement Screen is an accurate detector of body movement deficits and functional asymmetries.
6. The running economy protocol is a valid measure of aerobic energy demand while running.
7. The subjects were at a steady state pace during the last minute of each running trial.

Hypotheses

The study was designed to test the following hypotheses:

1. Endurance runners with functional movement asymmetries will have poorer running economy than runners with no measured movement asymmetries.

2. Endurance runners with an overall FMS score of 14 or less will have poorer running economy than runners with an overall FMS score of 15 or higher.

3. Endurance runners who score a 2 or less on the Hurdle Step test will have poorer running economy than runners who score a 3 on the Hurdle Step test.

Definition of Terms

Aerobic energy system- metabolism with oxygen present

Functional Asymmetry-" a consistent task discrepancy between non-dominant and dominant lower limbs" (Sadeghi, Allard et al. 2000).

Functional Movement Screen- " A pre-participation tool designed to identify functional movement deficits and asymmetries that may be predictive of general musculoskeletal conditions and injuries, with an ultimate goal of being able to modify the identified movement deficits through individualized exercise prescription" (Cook, Burton et al. 2006).

Running Economy- "The energy cost of movement at a given pace" (Morgan 1989).

CHAPTER 2: REVIEW OF LITERATURE

Running Economy

Running economy is the aerobic demand needed at a steady state running pace (Daniels 1985). Runners with good running economy use less energy and therefore consume less oxygen than runners with poor running economy at the same velocity, taking body mass into consideration (Saunders 2004). Efficient utilization of available energy allows for top performance in endurance running (Daniels 1985). In order for this to happen there must be a high capacity for energy transfer to muscles (Daniels 1985). In addition, it is desirable for the endurance runner to minimize counter-productive muscular movement (Daniels 1985). Running economy is represented by the energy expenditure and expressed as the submaximal VO_2 at a given running velocity (Conley and Krahenbuhl 1979). According to Saunders, under controlled conditions, running economy is a stable test capable of detecting relatively minor changes produced by training or other interventions (Saunders 2004).

There is a strong association between running economy and distance running performance (Saunders et al. 2004). Running economy is considered, by some researchers, an even better predictor of performance than maximal oxygen uptake (VO_2max) in elite runners (Costill, Thomason et al. 1972). Further, being able to describe the VO_2 at a set pace allows for comparison between individual runners (Daniels 1985). Dill suggested an up to 50% variation in oxygen cost of running between individuals (Dill, Talbott et al. 1930). When VO_2 is expressed as ml/min/kg, the individual variation is up to 30% (Dill, Talbott et al. 1930). Intra-individual variation in runner economy can be affected by time of testing, nutritional status, prior physical activity, and treadmill experience (Morgan 1989).

Saunders tested two international caliber 10km runners and found even though they had similar VO_2max values, the runner with the better running economy also had a one-minute faster 10km time (Saunders 2004). The comparison of oxygen uptake between the two runners can be seen in Figure 1 below.

Figure 1.

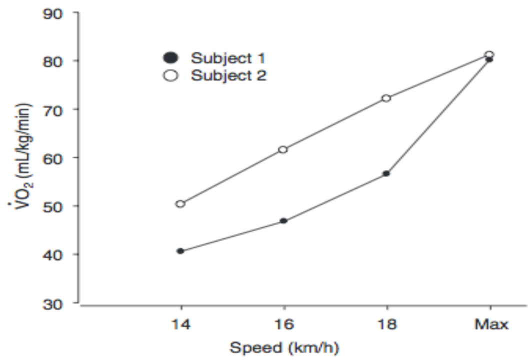


Fig. 1. Comparison of oxygen uptake ($\dot{V}O_2$) [mL/kg/min] in two international calibre 10km runners, one with good economy (subject 1) and the other with poor economy (subject 2) [Saunders et al. unpublished data, 2003]. **Max** = maximum.

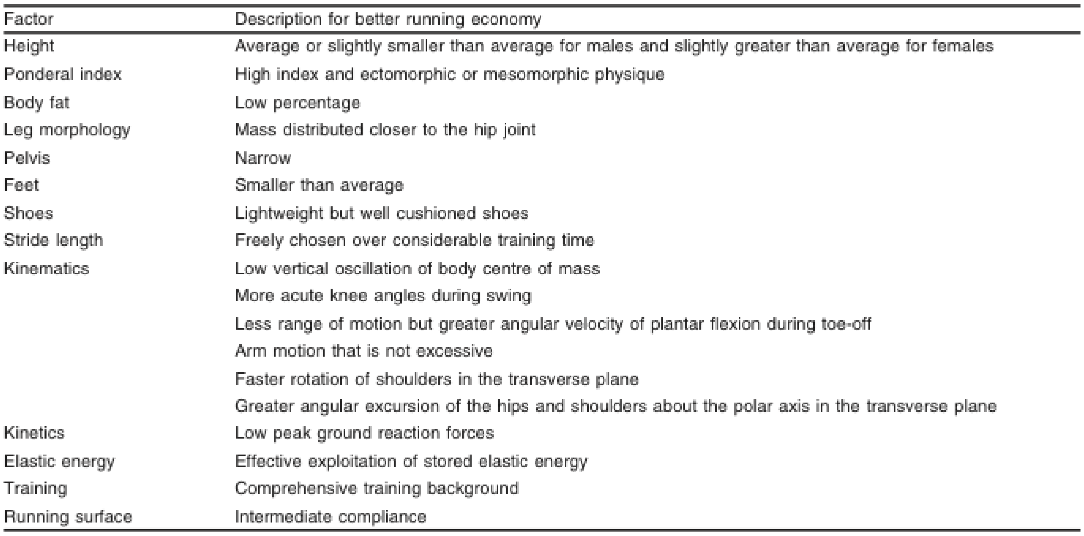
Numerous factors have been identified that contribute to running economy. When considering physiological and biomechanical factors, metabolic adaptations, elastic energy usage, and joint mechanics are important contributors. Morgan suggested heart rate, blood lactate levels, core temperature, and ventilation are the main physiological factors that influence running economy (Morgan 1989). When Thomas et al. tested these factors after a 5k run, all of them increased significantly, while running economy significantly decreased by the end of the run (THOMAS, Fernhall et al. 1999). However, ventilation was the only factor that correlated moderately with the decrease in running economy (THOMAS, Fernhall et al. 1999). This implies that with increased ventilation there is also an increased oxygen cost to the body.

Muscle fiber composition has also been shown to play a role in running economy. Runners with a higher percentage of slow-twitch fibers have been associated with better running economy (Cavanagh 1987), (Bosco, Montanari et al. 1987), (Kaneko 1990). This may mean that muscle fiber contraction speed and metabolic activity influence running economy (Saunders et al. 2004).

To continue, biomechanics play a large part in running economy. “Running involves the conversion of muscular forces translocated through complex movement patterns that utilize all the major muscle joints in the body” (Saunders 2004). The spring-mass model, an important factor associated with running economy, is where the bounce of the body on the ground is counteracted by the spring-like behavior of the support leg (Saunders et al. 2004). During the eccentric phase of contact, mechanical energy is stored in the muscles, tendons and ligaments (Saunders et al. 2004). Recovery during the concentric phase of the stored elastic energy reduces the energy cost of running (Saunders et al. 2004). This ability to store and release elastic energy is controlled by muscle stiffness (Saunders et al. 2004).

Below is a table from Saunders et al. that illustrates the major biomechanical factors involved in running economy (Saunders et al. 2004).

Figure 2.

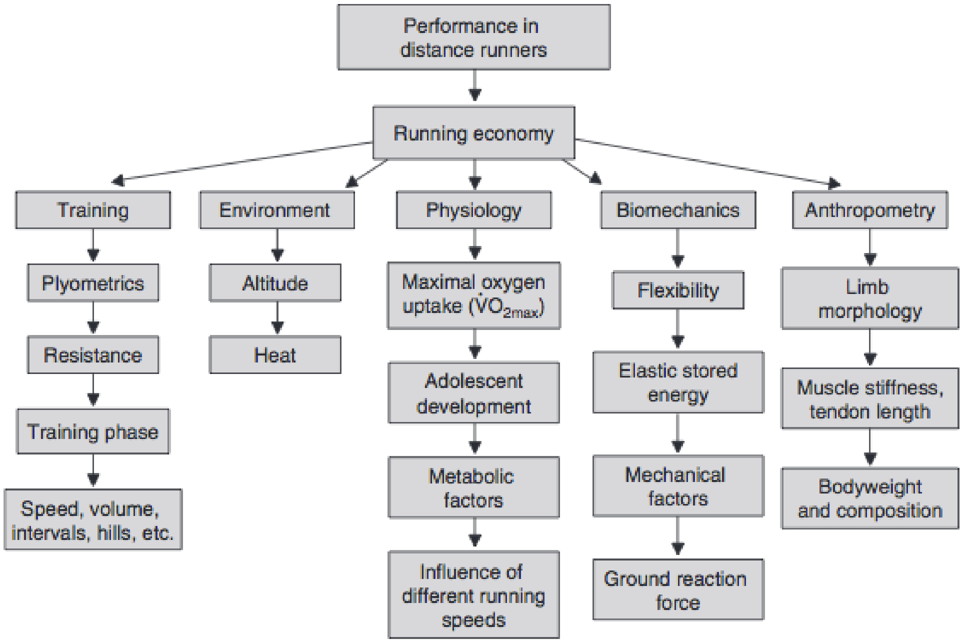


Factor	Description for better running economy
Height	Average or slightly smaller than average for males and slightly greater than average for females
Ponderal index	High index and ectomorphic or mesomorphic physique
Body fat	Low percentage
Leg morphology	Mass distributed closer to the hip joint
Pelvis	Narrow
Feet	Smaller than average
Shoes	Lightweight but well cushioned shoes
Stride length	Freely chosen over considerable training time
Kinematics	Low vertical oscillation of body centre of mass
	More acute knee angles during swing
	Less range of motion but greater angular velocity of plantar flexion during toe-off
	Arm motion that is not excessive
	Faster rotation of shoulders in the transverse plane
	Greater angular excursion of the hips and shoulders about the polar axis in the transverse plane
Kinetics	Low peak ground reaction forces
Elastic energy	Effective exploitation of stored elastic energy
Training	Comprehensive training background
Running surface	Intermediate compliance

More recently, Inen et al. explored biomechanical factors affecting running economy (LA INEN, Belli et al. 2001). In their study, 17 young endurance runners ran at 12-13 different running speeds while respiratory gases were collected, kinematic records were obtained using a high-speed video camera, and 3-D ground reaction forces (GRF) were measured simultaneously with EMG recordings of the selected leg muscles (LA INEN, Belli et al. 2001). As expected, they found an increasing linear relationship between running speed and oxygen consumption. The horizontal force in the braking phase was the largest running economy factor (82.1%) (LA INEN, Belli et al. 2001). As speed increased there was shortening contact times, increased stride frequency, increased contribution of stretch reflexes, and minor angular displacements in the ankle and knee joint in the braking phase which increased demand from the neuromuscular system (LA INEN, Belli et al. 2001). Stiffer muscles around the ankle and knee joint in the braking phase caused further force potentiation in the push-off phase (LA INEN, Belli et al. 2001).

Perl and Daoud et al. investigated footwear and foot strike type effects on running economy. They found that humans run more economically either barefoot or in minimal shoes than in standard shoes (Perl, Daoud et al. 2012). They chose to analyze foot strike type because rearfoot strike (RFS) and forefoot strike (FFS) gaits have slightly different mass–spring mechanics (Perl, Daoud et al. 2012). Tendons, ligaments, and muscles of the lower extremity store elastic energy during the first half of stance and then recoil during the second half of stance, helping push the body's center of mass upward and forward (Biewener, Farley et al. 2004). This may be used more effectively in barefoot or FFS running due to more elastic energy storage in the Achilles tendon, which recovers approximately 35% of the mechanical energy that the body generates with each step (Alexander 1991). During the last few decades, running shoes have been made more comfortable by using stiff soles and adding arch supports, but it is possible that these features interfere with the natural function of the foot (Perl, Daoud et al. 2012). This explains why most elite runners use lightweight minimal footwear with flexible soles and minimal arch support when they race (Perl, Daoud et al. 2012). Conversely, Frederick and Clarke et al. showed up to a 2.8% reduction in oxygen demand when runners wore well-cushioned shoes (Frederick, Clarke et al. 1983). They explained that non-cushioned shoes require more shock absorbance and more work for the muscles (Frederick, Clarke et al. 1983).

Figure 3.



In Figure 3 above, Saunders et al. summarized the numerous factors linked to running economy (Saunders et al., 2004).

In order to test running economy, motorized treadmills have been preferred over overground running (Saunders 2004). Although there are apparent test condition differences when using a treadmill instead of the ground, there is a high correlation between the running economy values (Saunders et al. 2004). Saunders described how runners performing overground used more hamstring contribution in order to get adequate propulsive forces (Saunders et al. 2004). Furthermore, indoor running eliminates wind and air resistance, which may lower physical demand and therefore lower oxygen consumption. Costill and Fox reported a 15% submaximal VO_2 difference when testing in no wind and simulated wind conditions (DL 1969).

Running economy has been a topic of interest for a long time. Nearly 100 years ago, Sargent calculated minute VO_2 to increase at the 3.8 power of speed, explaining the curvilinear relationship of VO_2 and running velocity (Sargent 1926). In the 1930s, Fenn suggested that the kinetic energy from limb movement during running made up a large portion of the total energy required (Fenn 1930). This implies that mechanics and gait patterns can affect energy expenditure. In 1958, Robinson et al. measured lactic acid accumulation in runners to explain the concept of starting a middle distance race slower and ending the race faster, due to the oxygen demand and lactic acid elevation when there is a change in the body's physiological state (Robinson, Robinson et al. 1958) . The roots of running economy were established a long time ago, but there is still much to be learned about the oxygen cost of running.

Functional Movement Screen

Functional movement screening (FMS) is a series of 7 movements designed to assess the quality of fundamental movement patterns and presumably identify an individual's functional limitations or asymmetries (Cook, Burton et al. 2006). The FMS, introduced in 2001 by Cook, has transformed screening for biomechanical deficits. This screen is able to simultaneously evaluate joint mobility and stability through functional movements that address the entire body. Comprehensive movements and core stability are evaluated to determine an individual's functional foundation (Chorba, Chorba et al. 2010). In his book *Movement*, Cook explains the importance of building a movement base, then developing supportive energy systems, and only after those exist should any skill-specific work be done (Cook 2010).

A score of 14 on the Functional Movement Screen, determined by Kiesel, has been generally accepted as the cut-off score for injury, meaning that a score of 14 or less increases risk of injury for that athlete. Lower FMS scores may imply more existing musculoskeletal deficits than higher FMS scores. Kiesel demonstrated that low FMS scores are associated with serious injury in American football players through a retrospective study done on one NFL team (Kiesel, Plisky et al. 2007). The study concluded that a score of 14 or less on the FMS was associated with an 11-fold increase in the chance of injury and a 51% probability of sustaining a serious injury over the course of one competitive season (Kiesel, Plisky et al. 2007). In 2007, Chorba et al. examined 38 female collegiate volleyball, basketball, and soccer players who performed the FMS (Chorba, Chorba et al. 2010). Lower scores on the FMS were significantly associated with injury, with 69% of those scoring 14 or less sustaining an injury, and experiencing a 4-fold increase in injury risk (Chorba, Chorba et al. 2010).

But not all research has reported FMS as a predictor of injury. One study looked at this topic specifically with 112 male and female high school basketball players and FMS performance (Sorenson 2009). Data analysis revealed that the commonly-used FMS cutoff score of less than 14 out of 21 was not significantly related to the likelihood of sustaining an injury, $p>.50$ (Sorenson 2009). The FMS displayed very poor ability to predict at-risk athletes, as a greater percentage of those scoring fourteen or higher became injured (24%) compared to those below the cutoff (22%) (Sorenson 2009). These data contradict the previous claim established by Kiesel (Sorenson 2009). More research is needed to establish and validate a cutoff score that can be widely accepted, even if that means different sports require different cutoff scores.

The Hurdle Step test was looked at specifically in this study due to the movement closely reflecting many aspects of running. The hurdle step and single-leg stance patterns demonstrate the necessary mobility and stability needed for stepping, climbing, and running (Cook 2010). Cook explains how runners usually only work on specific running mechanics, rather than considering fundamental mobility and stability (Cook 2010). He found it surprising how common it is for runners to have no reflex stabilization in single-leg stance on one or both legs (Cook 2010). This has implications of wasted energy that translates to poorer running economy. Excessive running on an incorrect foundation can cause a lack of reflex stabilization, which can be observed in the Hurdle Step test. Excessive muscle tightness can cause muscle imbalances throughout the body. Muscle stiffening in the extremities is caused by inefficient core reactions (Cook 2010). Repeated running then reinforces the stiffness because it is compensatory (Cook 2010). Since stiffness is reinforced throughout conditioning, stretching would not fix this issue (Cook 2010). According to Cook, a poor score or asymmetrical score on the Hurdle Step test can imply both reflex stabilization and muscle tightness problems (Cook 2010).

The Functional Movement Screen is a quick, inexpensive, noninvasive, and appropriate way to rate movement limitations and asymmetries. Altered mobility, stability, and asymmetrical influences eventually lead to compensatory movement patterns, often leading to injury (Cook 2010). Early detection of fundamental problems in endurance runners would allow for an intervention including corrective exercises based on specific deficits found. This could prevent later injuries and/or declines in performance due to these deficits. Therefore, although not yet shown, using the FMS as a preseason assessment has the potential to prevent injury and yield better running economy.

Asymmetries

Asymmetries in the body suggest unevenness in either structural or functional components (Cook 2010). These irregularities between left and right side can be easily detected during the FMS by a trained eye. Structural asymmetry, such as leg-length discrepancy, has received much more attention in the past than functional, movement-based asymmetry (Cook 2010). As expected, functional asymmetries are generally easier to fix than structural asymmetries. When both of these types of asymmetries are present, corrective strategies can have a significant influence on functional asymmetries, and even reduce structural declines, acting as a preventative measure (Cook 2010). Asymmetrical behavior of the lower limbs during ambulation has been found to reflect natural functional differences between the lower extremities (Sadeghi, Allard et al. 2000).

Kiesel showed that low FMS scores in NFL players are significantly associated with injury. Although asymmetries in the FMS were specifically assessed and recorded, no statistical evidence supported asymmetry as a risk factor for injury among NFL players (Kiesel, Plisky et al. 2007). Kiesel still suggested that correcting asymmetries and remediating problematic movements might be crucial for any intervention to mediate risk of injury (Kiesel, Plisky et al. 2007). Similarly, Burton, a FMS developer, found that FMS movement asymmetries were not significant predictors of injury in a population of firefighters (Burton 2006). More research about asymmetries with larger sample sizes is needed.

Reliability

Reliability studies for the FMS have been conducted, both in intra-rater reliability and inter-rater reliability. Generally the FMS conductors that have the most clinical experience (regardless of FMS experience) have the best reliability results (Brigle 2010). The FMS has shown to have an intra-rater reliability ICC range of 0.74-0.91(Shaffer, Teyhen et al. 2010, Teyhen, Shaffer et al. 2010, Teyhen, Shaffer et al. 2012). Inter-reliability results vary across studies based on methods used and experience of the conductor. Overall, most studies report moderate to good inter-rater reliability (Minick, Kiesel et al. 2010, Teyhen, Shaffer et al. 2010). The reliability of the FMS is important for future clinicians, and it supports the validity of the test.

CHAPTER 3: METHODS

Subjects

Forty men and women subjects between the ages of 18 and 35 were tested. From a questionnaire of exercise habits, all subjects indicated that they ran a minimum of 30 miles per week for the past 6 weeks. To be included in the subject cohort, men had to have a VO_2max of 55 ml/kg/min or more and women 50 ml/kg/min or more. Each subject confirmed that they did not have any musculoskeletal injuries that interfered with their running abilities in the 6 weeks prior to testing. To the best of their knowledge, subjects were not suffering from any physical ailments or injuries that would hinder their performance in this study. Prior to participation, all subjects signed an informed consent form approved by the Indiana University Institutional Review Board, which approved this study.

Procedures

All subjects filled out two questionnaires prior to testing. The Modified Physical Activity Readiness Questionnaire (PAR-Q) asked about health status while being physically active. The physical activity questionnaire asked about running and treadmill usage history. Subject height (cm) and weight (kg) and shoe weight (kg) were recorded before testing began. After the subject filled out the questionnaire, body composition was assessed by bioelectrical impedance analysis (BIA). Each subject completed the FMS and then performed the running economy test. Each subject then finished with a VO_2max test on a motor driven treadmill (Quinton, Bothell, WA). Each subject came into the lab for testing on only one occasion in climate controlled, indoor laboratory.

BIA

Each subject’s body composition was estimated using BIA (Tanita, MC780, Arlington Heights, IL). The subject was at a resting state for at least 5 minutes before being tested. After the subject’s height (cm), weight (kg), sex, and body type were entered into the Tanita, the subject stood still on the scale and grasped the hand probes. The Tanita took about 10 seconds to measure and print out the results. The Tanita measured resistance and reactance throughout the subject’s body. Total body water, fat-free mass, and fat mass percentage were calculated to estimate body composition (Horlick, Arpadi et al. 2002).

Functional Movement Screen

Functional Movement Screens were completed as described by Cook (Cook, Burton et al. 2006). Subjects completed all seven movements of the screen in the order listed below, with each movement being completed 3 times until the evaluators were confident in his or her score. Clearing tests were performed after the Shoulder Mobility, Trunk Stability Push Up, and Rotary Stability movements in order to rule out any shoulder impingement or back pain. Each subject performed the test in front of two evaluators. The evaluators were trained and certified in FMS by The Functional Movement Systems. Scores were decided individually and compared between evaluators after each movement to ensure consistency. Each movement was given a whole number score by the evaluator between 0 and 3, based on scoring criteria as described by Cook (Cook, Burton et al. 2006), (see Appendix A-G). A score of 0 was given if there was any pain during the movement or during the clearing tests. In the five bilateral movements, a score was recorded for both left and right side with the lowest score being used in summation for a total score. Instructions and demonstrations were provided for each FMS test, so a clear understanding was ensured before the subject started the test.

1. Deep Squat- This movement tested bilateral, symmetrical, functional mobility and stability of the hips, knees and ankles. (Starting position) The subject placed the instep of their feet in vertical alignment with the outside of the shoulders, with no lateral outturn of the toes. The subject rested the dowel on top of the head, with elbows bent at a 90-degree angle. (Movement) The subject pressed the dowel overhead, shoulders flexed and abducted and elbows fully extended. The subject was instructed to slowly descend into the deepest possible squat position with heels on the floor, head and chest facing forward, and the dowel maintained overhead. Knee valgus should have been avoided. The subject was allowed three attempts. A score of three was given if the subject could maintain alignment of the dowel overhead, knees aligned over feet, femur achieved below parallel to the ground, and upper torso was parallel with tibia. If any of the movement criteria was not met on the first attempt, the subject performed the squat with the FMS board under their heels. If successful, the subject received a score of two. If any criteria were not met with use of the board, the subject received a score of one. A score of zero was given for any pain experienced throughout the exercise (Cook 2010). Please reference Appendix A.

2. Hurdle Step- This movement tested bilateral mobility and stability of the hips, knees, and ankles. It also challenges stability and control of the pelvis and core. This was tested on both sides of the body. (Starting position) A height measurement of the subject's tibia (tibial tuberosity) was taken first to determine hurdle cord height. The subject stood directly behind the center of the hurdle base, with feet touching at heels and toes. The toes were aligned and touched the base of the hurdle. The dowel was placed across the shoulders but below the neck. (Movement) The subject was instructed to step over the hurdle to touch the heel to the floor while maintaining a straight spine, and then return the leg to the starting position. The subject was allowed three attempts. A score of three was given if the subject maintained proper balance, the dowel and hurdle cord remained parallel, and there was no alignment lost between the ankles, knees, and hips. A score of two was given if there were any criteria not met. A score of one was given if there was a complete loss of balance or if the subject hit the hurdle. A score of zero was given for any pain experienced throughout the exercise (Cook 2010) . Please reference Appendix B.

3. In-line Lunge- This movement tested the mobility and stability of the hip, knee, ankle, and foot. It also challenges the flexibility of multi-articular muscles (latissimus dorsi and rectus femoris). The tibia length measurement was used from the previous hurdle step test. This was tested on both sides of the body, and the front leg identifies the side that was scored. (Starting position) The subject placed the toe of the back foot at the start line on the FMS board, and heel of the front foot at the appropriate mark based on tibia length. The dowel was placed behind the back, touching the head, thoracic spine, and sacrum. The subject placed their hand that was opposite the front foot around the dowel at the cervical spine.

The subject's other hand grasped the dowel at the lumbar spine. (Movement) The subject was instructed to lower the back knee to touch the board behind the heel of the front foot, and return to the starting position. The subject was allowed three attempts. A score of three was given if the dowel maintained vertical position and contact with head, thoracic spine and sacrum, there was no loss of balance, the back knee touched the board, the front heel remained in contact with the board, and the back heel touched the board on return of movement. A score of two was given if any of the criteria were not met. A score of one was given if there was a complete loss of balance and inability to complete the movement. A score of zero was given for any pain experienced throughout the exercise. (Cook 2010). Please reference Appendix C.

4. Shoulder Mobility- This movement tested bilateral shoulder range of motion; extension, internal rotation, and adduction of one arm, and flexion, external rotation, and abduction of the other. This was tested on both sides of the body, and the top shoulder identifies the side that was scored. (Starting position) The subject's hand length was measured in inches with the dowel from the distal wrist crease to the tip of the longest digit. The subject stood with feet together, and made a fist with each hand, thumbs inside the fingers. (Movement) The subject was instructed to simultaneously reach one fist behind the neck and the other behind the back, assuming maximal adduction, extended, and internally rotation in one shoulder and maximal abduction, flexion, and external rotation in the other shoulder. The subject stayed in this position while the distance between the subject's fists at the closest point was measured using the dowel. The subject was allowed three attempts. A score of three was given if the subject moved in one smooth motion, fists remained still and closed after

placement, and fists were within one hand length. A score of two was given if the subject's fists were within one and a half hand lengths. A score of one was given if the subject's fists were farther than one and a half hand lengths. After completing this test, every subject performed the shoulder clearing assessment to rule out any shoulder impingement. The subject placed the hand on the opposite shoulder and then flexed the shoulder, bringing the elbow towards the face. A score of zero was given for any pain experienced throughout the exercise (Cook 2010) . Please reference Appendix D.

5. Active Straight Leg Raise- This movement tested active hamstring and gastroc-soleus flexibility, and pelvis and core stability. This was tested on both sides of the body, and the leg that was lifted identified the side that was scored. (Starting position) The subject lied supine with the arms by side, head down, head flat on the floor, and the palms of hands up. The FMS board was placed under both knees. Both feet were in neutral position, with soles of the feet perpendicular to the floor. A dowel was placed perpendicular to the ground at the point between the anterior superior iliac spine and the knee joint line. (Movement) The subject was instructed to lift the test limb while maintaining the original start position of the ankle and knee of other limb. At end-range of motion the position of the lateral malleolus relative to the non-moving limb was observed. The subject was allowed three attempts. A score of three was given if the lateral malleolus passed the dowel, the non-moving knee remained in contact with the board, the toes remained pointing upward, and the head remained flat on the floor. A score of two was given if the non-moving limb did not remain extended or it rotated to assist lifting the other limb, and the subject's lateral malleolus must have passed the dowel when placed between mid-thigh and patella. If the subject's lateral

malleolus was unable to pass the dowel when placed between mid-thigh and patella, a score of one was given. A score of zero was given for any pain experienced throughout the exercise (Cook 2010). Please reference Appendix E.

6. Trunk Stability Push-Up- This movement tests stabilization of the spine while doing a closed kinetic chain upper body symmetrical pushing action. (Starting position) Subject lied prone with arms extended overhead. Men started with thumbs in line with the top of the forehead. Women started with thumbs in line with the chin. The knees were full extended, ankles neutral, and soles of feet perpendicular to the floor. (Movement) The subject was instructed to perform one full push-up. The subject was allowed three attempts. A score of three was given if the subject performed the push-up with hands at forehead and the entire body was lifted as one unit with no lag or sway. If the pushup is performed with hands at chin level then a score of two was given. If any of the criteria for a score of two were not met, then a score of one was given. A clearing test was performed after the trunk stability push-up test was completed. The subject lied prone on the floor, extended the spine while maintaining pelvic contact with the floor, and fully extended the elbows. A score of zero was given for any pain experienced throughout the exercise (Cook 2010). Please reference Appendix F.

7. Rotary Stability- This movement tested multi-plane pelvis, shoulder, and core stability during combined upper extremity and lower extremity movement. It also tested reflex stabilization and weight shifting in the transverse plane. This was tested on both sides of the

body, and the upper moving arm identified the side that was scored. (Starting position) The subject was quadruped on the floor with the FMS board between the hands and knees. The hips and shoulders were positioned at 90-degrees relative to the trunk, with the ankles neutral and soles of feet perpendicular to the floor. The subject's hands were open and the thumbs, knees, and feet all touched the FMS board. (Movement) The subject was instructed to flex the shoulder and extend the hip and knee of the same side of the body, and then bring the elbow to the knee. The subject was allowed three attempts. A score of three was given if the same-side knee and elbow touched with body in line over the board, while maintaining a flat spine and hips and shoulders bent at 90-degrees. A score of two was given if the subject performed the movement with diagonal arm and leg, instead of same-side limbs. The elbow and knee did not have to touch for a score of two. If the subject was unable to complete this movement or lost balance, a score of one was given. A clearing test was performed after the rotary stability movement was completed. From quadruped, the subject moved buttocks to heels and chest to thighs. Shoulders were extended as far as possible in front of the body. A score of zero was given for any pain experienced throughout the exercise (Cook 2010). Please reference Appendix G.

Running Economy

This procedure tested the oxygen uptake at submaximal running velocities. When calculating running economy, a linear relationship between the rate of oxygen uptake and running speed was assumed. The subject warmed up on the treadmill at a self-selected pace for five minutes. They were equipped with a Polar heart rate monitor (#FT1, Polar Electro Inc., Lake

Success, NY) and a Hans Rudolph facemask (#2700, Hans Rudolph, Shawnee, MO). The subject ran three four-minute bouts at speeds of 10, 12, and 14 km/hour for women and 12, 14, and 16 km/hour for men. These speeds were chosen because they allowed the subject to be at steady state, with minimal energy contribution from anaerobic metabolism (Saunders 2004). The subject was given three minutes of standing rest between each four minute running stage. Metabolic information was obtained throughout the entire test, but only the last minute of each trial was used to calculate running economy.

Running economy was calculated in three separate ways; VO_2 in units of ml/kg/min, slope of the VO_2 versus speed relationship, and VO_2 in units of ml/kg/km. The average of the 3 test speeds was used for VO_2 ml/kg/km.

Maximal Oxygen Uptake Test

The subject performed a maximal oxygen uptake (VO_2max) test immediately following the last stage of the running economy test. The subject stayed running constantly at either 16 km/hour (men) or 14 km/hour (women), but the grade was taken to 2% in the first minute, then increased by 2% every 2 minutes until the subject reached volitional exhaustion. The criteria for establishing maximal oxygen consumption included 1. A plateau in oxygen consumption with increasing workload, specifically a difference in last 2 consumptions by less than 150ml· min-1 or 2.1ml·kg·min-1 (Powers and Howley 2004). · 2. A respiratory exchange ratio greater than 1.05 - 1.15 (Powers and Howley 2004). 3. A heart rate within 10-12 bpm of age predicted maximal heart rate (HRmax = 220-age) (Durstine, Pate et al. 1988).

Instrumentation

Bioelectrical impedance (Tanita, MC780, Arlington Heights, IL) was used to estimate body composition.

The Functional Movement Screen kit was used to complete the first part of this study. This kit included a 2x6 foot wooden board, plastic and elastic cord (to create a hurdle), and a 4-foot long dowel rod used for the deep squat, hurdle step, in-line lunge, shoulder mobility, and active straight leg raise movement tests.

Ventilatory and metabolic variables were continuously measured and monitored during exercise using a computer interfaced, open circuit, indirect calorimetry system, and heart rate was monitored via telemetry (#FT1, Polar Electro Inc., Lake Success, NY). Minute ventilation was determined using a pneumotach (Series 3813/4813, Hans Rudolph, Shawnee, KS) on the inspired line. Subjects wore a face mask and breathed through a low resistance, two-way valve (#2700, Hans Rudolph, Shawnee, MO), and a 5-liter mixing chamber was used for the collection of expired gases. Fractional concentrations of O_2 and CO_2 were determined from dried expired gas, sampled at a rate of $300\ ml{\cdot}min^{-1}$, using separate O_2 and CO_2 gas analyzers (Ametek Thermox Instruments, Pittsburgh, PA). Analyzers were calibrated prior to each test and between workloads using commercially available gas mixtures within the physiological range. VE, VO_2, and VCO_2 were measured over each minute of exercise, with VE corrected to BTPS and VO_2 and VCO_2 corrected to STPD. The above variables, as well as FEO_2 as $FECO_2$, were continuously measured and monitored with a data acquisition control system (DASYLab 10.0, National Instruments, Norton, MA) sampling at 50 Hz.

Statistical Analysis

Subjects were placed into independent groups based on the following criteria: 1) asymmetry or no asymmetry, based on differences in the left and right side scores of the five bilateral movements. At least one asymmetry in any of the five bilateral tests placed subjects in the asymmetry group. 2) FMS total score $\leq$ 14 or > 14.   Numerous studies have named a total score of 14 as the cut-off score, and lower than that implies greater injury risk (Kiesel, Plisky et al. 2007). 3) Hurdle Step score 3 or <3. 50 independent t-tests (two-tailed) were used to determine differences between groups at each running speed for all 3 dependent variables; asymmetry or no asymmetry, FMS total score of $\leq$ 14 or > 14, and Hurdle Step score 3 or <3. Also, 64 correlations were conducted between numerous variables and performance outcomes. The alpha for statistical significance was set at $p < 0.05$.

CHAPTER 4: RESULTS

Subject and Group Characteristics

A total of 40 (24 men and 16 women) well-trained endurance runners met the inclusion criteria for the study. Subject characteristics can be found in Table 1. VO_{2max} was 63.1 ± 6.9 ml/kg/min (mean ± SD) for men and 58.4 ± 7.4 ml/kg/min for women. The asymmetrical group had 21 subjects with 15 being men and 6 being women. The symmetrical group had 19 subjects with 9 being men and 10 being women. The total score of 15 or more group had 37 subjects with 22 being men and 15 being women. The total score of 14 or less group had 3 subjects with 2 being men and one being women. The hurdle step score of 3 group had 19 subjects with 12 being men and 7 being women. The hurdle step score of < 3 group had 21 subjects with 12 being men and 9 being women. All subjects ran a weekly mileage of at least 30 miles.

Table 1. Subject Demographics

	Men (n=24)	Women (n=16)	Overall (n=40)
Age (years)	23 ± 4	25 ± 5	24 ± 4
Height (cm)	176.4 ± 5.6	163.0 ± 6.9*	171.1 ± 8.9
Mass (kg)	68.7 ± 7.9	53.5 ± 6.5*	62.7 ± 10.5
VO_{2max} (ml/kg/min)	63.1 ± 6.9	58.4 ± 7.4*	61.2 ± 7.4
FMS Score	16.8 ± 1.9	17.8 ± 1.7	17.2 ± 1.9
Body Fat (%)	9.1 ± 5.5	14.3 ± 5.0*	11.2 ± 5.9

Values are mean ± SD
* = Significantly different from men, $p < 0.05$

Asymmetrical Versus Symmetrical

There was a significant difference in running economy between the asymmetrical group (n=21) and the symmetrical group (n=19), when combining men and women, only at the speed of 14 km/hour (Figure 4, Tables 3 through 5). Contrary to our original hypothesis, the asymmetrical group was more economical than the symmetrical group. Comparing running economy between asymmetrical and symmetrical FMS scorers (men and women together and separately) at all other speeds did not show any significant difference, although the consistently lower VO_2 values in the asymmetrical group was approaching significance (p = 0.12 – 0.15) at several speeds. Power analyses indicate approximately 10 additional subjects needed to show significance at the power observed throughout this study.

Figure 4.

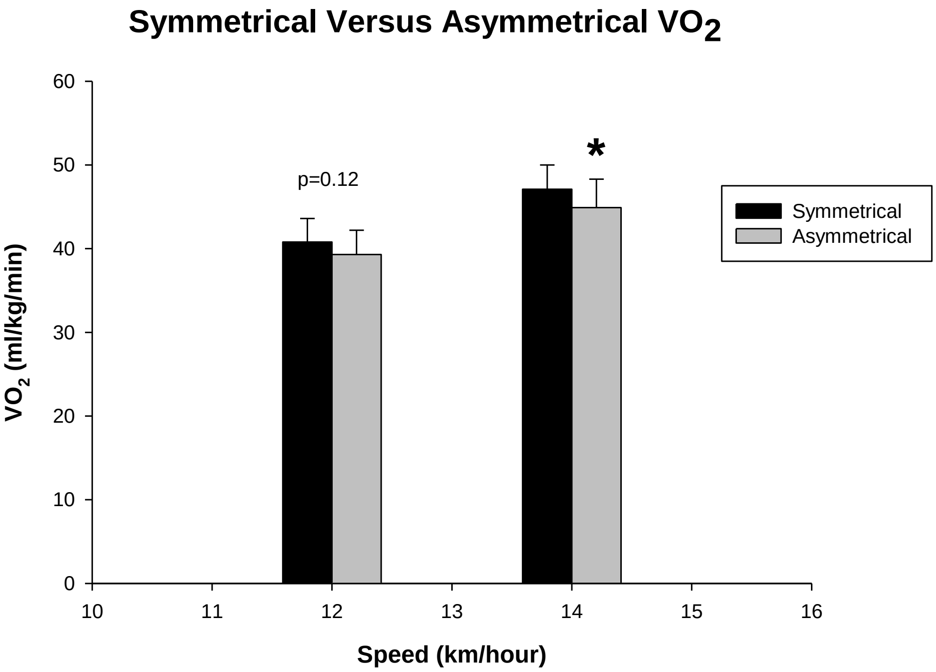


Table 2. FMS Asymmetries

FMS Test	**n**
Hurdle Step	4
In-line Lunge	4
Shoulder Mobility	9
Active Straight Leg Raise	14
Rotary Stability	1

Table 3. Distribution of FMS Asymmetries within subjects

Asymmetries	**n**
None	19
One	12
Two	7
Three	2
Four	0
Five	0

FMS Hurdle Step 3 Versus FMS Hurdle Step ≤ 2

There was no difference between running economy of the FMS Hurdle Step test score of 3 group (n=19) and the FMS Hurdle Step test score of 2 or less group (n=21) at any speed (Tables 3 through 5).

FMS Total Score ≥ 15 Versus FMS Total Score ≤ 14

There was no difference between running economy of the FMS Total Score of 14 or less group (n=2) and the FMS Total Score of 15 or more group (n=38) at any speed (Tables 3 through 5). However, the FMS Total Score of 14 or less group consisted of only two runners, limiting our statistical power to show differences.

Table 4. Running Economy for Men and Women

Men and Women	**VO_2 12 km/h**	**p**	**VO_2 14 km/h**	**p**
Asymmetrical (n=21)	39.3 ± 2.9	0.12	44.9 ± 3.4*	0.04
Symmetrical (n=19)	40.8 ± 2.8		47.1 ± 2.9	
Total Score ≤14 (n=3)	39.6 ± 0.1	0.79	45.9 ± 1.7	0.99
Total Score ≥15 (n=37)	40.0 ± 3.0		45.95 ± 3.4	
HS Score 3 (n=19)	40.3 ± 2.7	0.59	46.3 ± 3.4	0.52
HS Score < 3 (n=21)	39.8 ± 3.3		45.6 ± 3.3	

Values are mean ± SD

*= significantly different from Symmetrical, $p < 0.05$

Table 5. Running Economy for Men

Men	VO_2 12 km/hour	p	VO_2 14 km/hour	p	VO_2 16 km/hour	p
Asymmetrical (n=15)	39.6 ± 2.9	0.32	44.7 ± 3.5	0.13	50.8 ± 3.9	0.15
Symmetrical (n=9)	40.7 ± 1.9		46.9 ± 2.7		53.1 ± 2.9	
Total Score ≤14 (n=2)	39.6 ± 0.2	0.8	45.5 ± 2.2	0.99	49.3 ± 0.4	0.35
Total Score ≥15 (n=22)	40.1 ± 2.8		45.6 ± 3.5		51.9 ± 3.7	
HS Score = 3 (n=12)	40.1 ± 2.7	0.96	45.7 ± 3.7	0.89	52.2 ± 3.7	0.54
HS Score < 3 (n=12)	39.9 ± 2.7		45.5 ± 3.2		51.2 ± 3.7	

Values are mean ± SD

Table 6. Running Economy for Women

Women	**VO$_2$ 10 km/hour**	**p**	**VO$_2$ 12 km/hour**	**p**	**VO$_2$ 14 km/hour**	**p**
Asymmetrical (n=6)	33.1 ± 2.4	0.84	38.6 ± 2.9	0.22	45.4 ± 3.3	0.29
Symmetrical (n=10)	33.4 ± 3.8		40.8 ± 3.5		47.3 ± 3.3	
Total Score ≤14 (n=1)	32.9 ± 0	0.92	39.6 ± 0	0.91	46.9 ± 0	0.93
Total Score ≥15 (n=15)	33.3 ± 3.4		39.9 ± 3.5		46.5 ± 3.4	
HS Score = 3 (n=7)	34.2 ± 2.2	0.32	40.6 ± 2.7	0.51	47.5 ± 2.7	0.36
HS Score < 3 (n=9)	32.6 ± 3.9		39.4 ± 3.9		45.9 ± 3.7	

Values are mean ± SD

Men Versus Women

At running speeds of 12 and 14 km/hour, the men (n=24) and women (n=16) did not have different running economies when reported in units of ml/kg/min, and ml/kg/km (Figure 5). The women had a significantly ($p = 0.04$) larger slope of VO_2 versus running speed, or change in running economy, at the same speeds as the men.

Table 7. Running Economy for Men

Men	**12 km/hour**	**14 km/hour**	**16 km/hour**
VO_2 ml/kg/min	40.0 ± 2.6	45.6 ± 3.4	51.7 ± 3.6
VO_2 ml/kg/km	200.1 ± 13.1	195.2 ± 14.4	193.8 ± 13.6
Slope ml/kg/min per km/hour	2.9 ± 0.7*		

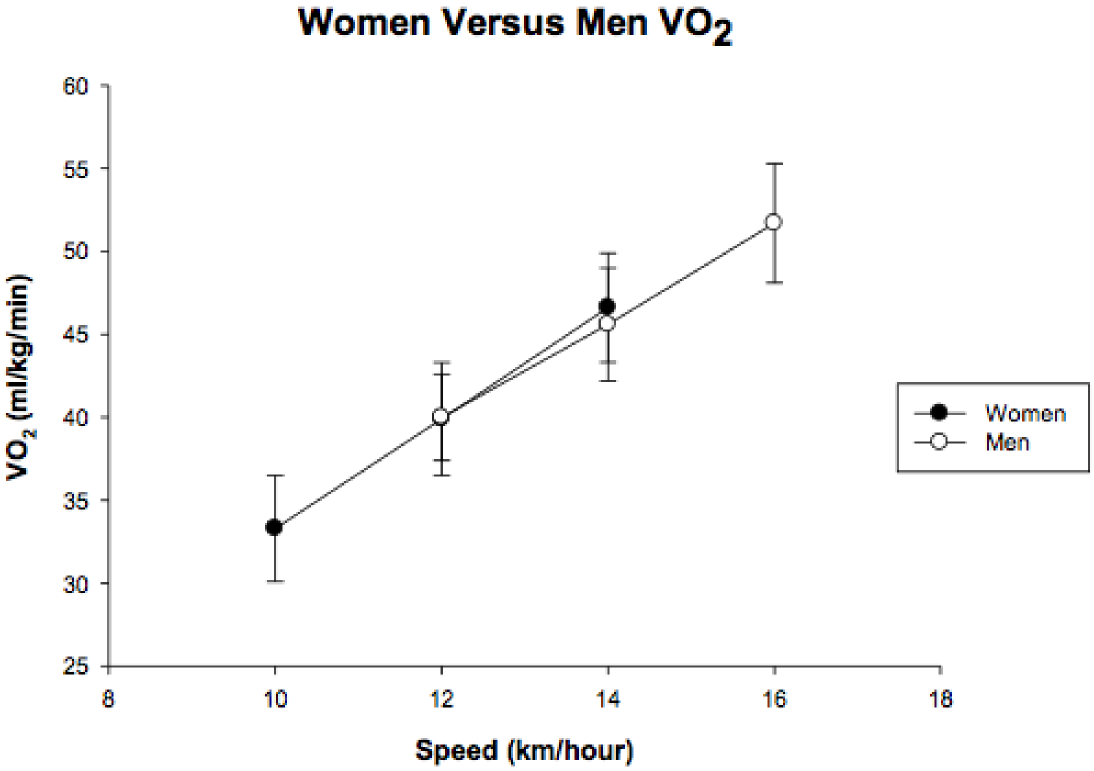
Values are mean ± SD
*= significantly different from Women, $p < 0.05$

Table 8. Running Economy for Women

Women	**10 km/h**	**12 km/h**	**14 km/h**
VO_2 ml/kg/min	33.3 ± 3.2	39.9 ± 3.4	46.6 ± 3.3
VO_2 ml/kg/km	199.7 ± 19.5	199.8 ± 16.9	199.5 ± 14.2
Slope ml/kg/min per km/hour	3.3 ± 0.4*		

Values are mean ± SD

Figure 5.



Correlations

Numerous correlations were analyzed using variables in this study. There was no correlation seen between the runner's shoe mass (kg) and running economy (r = -0.14, p = 0.40). Furthermore, shoe mass did not correlate with VO_{2max} (r = -0.10, p = 0.54). There was no correlation between VO_{2max} (ml/kg/min) and running economy (r = 0.06, p = 0.73). There was a negative correlation between VO_{2max} (ml/kg/min) and age (r = -0.39, p = 0.01), and also body fat percentage (r = -0.67, p = 0.01). Lastly, the Functional Movement Screen total score negatively correlated with both body weight (kg) (r = -0.49, p = 0.001) and height (cm) (r = -0.44, p = 0.005).

CHAPTER 5: DISCUSSION

The primary finding of this study was that well-trained endurance runners with movement asymmetries ran at a lower metabolic cost than runners with no movement asymmetries, but significantly lower only at the submaximal pace of 14 km/hour. These results opposed the original hypothesis that symmetrical runners would run more economically than asymmetrical runners. Gait data obtained from a study done concurrently showed that runners who were asymmetrical during the Functional Movement Screen also had larger asymmetries in ground contact times between left and right foot strikes during the running economy tests, compared to FMS symmetrical runners (Freeman 2015). Taken together these results suggest a link between Functional Movement Screen outcomes, endurance running mechanics, and the metabolic cost of running.

All three original hypotheses were disproven with opposite results. Runners with any asymmetries yielded a significantly lower running economy at 14 km/hour. A number of studies have shown that poor functional movement abilities – either movement asymmetries or lower total FMS scores – are linked strongly to greater injury incidence among athletes (Chorba, Chorba et al. 2010). This study attempted to extend the relationship between functional movement scores and actual movement asymmetries during a dynamic exercise task. Why asymmetrical subjects were more economical when running is not clear.

A potential explanation of the lower VO_2 in asymmetrical runners could lie in lower leg tightness. It has been shown that in a group of trained endurance runners, the most economical runners had higher stiffness in the lower leg tendon compared to the less economical runners (Cheng 1990, Dutto D.J. 2002, Kerdock A.E. and P.G. Weyand 2002, Arampatzis 2007). This is thought to be due to mechanical properties and increased ability to "recoil" elastic energy while running. Using the spring – mass model for running, it is possible to calculate vertical stiffness and leg stiffness using kinematic variables. Using a previously published model (Morin 2005) verified with measures of ground reaction forces, and kinematic data on our subjects from a companion study (Freeman 2015), we calculated:

Kvert (kN/m), vertical stiffness, defined as the ratio of the estimated peak vertical force (Fmax; kN) and the estimated center of mass displacement (Δyc; m).

Kleg (kN/m), leg stiffness, defined as the ratio of the estimated peak vertical force (Fmax; kN) and the estimated compression of the leg spring (ΔL, m).

Each of these values was estimated using the following formulas (Morin et al., 2005):

Kvert = Fmax / Δyc

Fmax = $mg\frac{\pi}{2}\left(\frac{tf}{tc}+1\right)$

Where m = body mass (kg), g = acceleration due to gravity, tf = flight time (s), tc = contact time (s)

Δyc = $\frac{Fmax \cdot tc^2}{m\pi^2}+g\frac{tc^2}{8}$

Kleg = Fmax / ΔL

ΔL = L - $\sqrt{L^2-\left(\frac{vtc}{2}\right)^2}+\Delta yc$

Where L = leg length (m), modeled as 0.53 * standing height (m) according to Winter (1979), and v = running velocity (m/s).

At both 12 m/s and 14 m/s, asymmetrical subjects showed a greater mean Kvert and Kleg, which approached statistical significance (p value range 0.08 – 0.13; table 8). These values are in line with previously published reports of leg stiffness being inversely proportional to metabolic cost while running (Cheng 1990, Dutto D.J. 2002, Kerdock A.E. and P.G. Weyand 2002).

Table 8. Calculated Stiffness Values

	Symmetrical (n=19)	Asymmetrical (n=21)	p (one-tail)
Kvert 12 km/h (kN/m)	16.11 ± 5.45	18.46 ± 6.20	0.11
Kleg 12 km/h (kN/m)	6.87 ± 2.42	8.06 ± 2.82	0.08
Kvert 14 km/h (kN/m)	20.57 ± 5.41	23.13 ± 8.19	0.13
Kleg 14 km/h (kN/m)	7.21 ± 2.02	8.36 ± 3.18	0.09

Values are means ± SD. Kvert, vertical stiffness; Kleg, leg stiffness.

However, it is important to note that while increased stiffness in the muscle-tendon complex of the lower leg can improve running economy, it could negatively affect range of motion. Generally, more flexible muscles and tendons will be more compliant and less stiff. The effects of limited mobility in the lower leg can disturb the Active Straight Leg Raise, In-Line Lunge, Hurdle Step, and Deep Squat Functional Movement Screen tests. Lower leg mobility of the runners in this study likely contributed to the asymmetries and lower scores seen during the Functional Movement Scree

Anatomically asymmetrical runners have been shown to run with more asymmetrical kinematics (Seminati 2013) . In line with our data, these asymmetrical runners did not have higher metabolic costs, suggesting that the body adapts (compensates) to structural changes in order to preserve economy (Seminati 2013). An anatomical asymmetry threshold to metabolic cost is yet to be determined. While the current study did not specifically measure anatomical differences of the runners, structural differences could have affected mobility and stability during the Functional Movement Screen. The Active Straight Leg Raise test displayed the most asymmetries (n=14) in this group of runners. This can likely be attributed to tight hamstring and gastrocnemius muscles, as well as core instability, often seen in runners. Shoulder Mobility asymmetries were the second most occurring (n=9), reflecting limited mobility of the shoulder joint, especially in the shoulder of the runner’s non-dominant hand side (self reports). The asymmetries seen in the Hurdle Step and In-Line Lunge tests (n=4) were likely affected functionally by tight hips and lower legs, core instability, or structurally (i.e. leg length discrepancy). Only one runner was asymmetrical during the Rotary Stability test, which encompasses core and spinal stability. A third of the runners with asymmetries (n=7) had unilateral deficits in both the Active Straight Leg Raise and the Shoulder Mobility tests. No other predictive trends involving asymmetries were observed.

Another possible explanation for the difference in running economy at 14 km/hour could be due to random effect of sampling, rather than actual differences between groups. However, differences between symmetrical and asymmetrical groups were approaching significance at other speeds and particularly within the group of men, suggesting differences are systematic rather than random. While the observed treatment effect is small, very small differences in running economy can have significant effects on running performance. For example, it has been shown that a 7.8% change in running economy can have a 2.8% change in performance (Paavolainen 1999). Therefore the 3-5% difference in running economy between the asymmetrical and symmetrical men, which not statistically significant with the number of subjects screened in this study, may hold practical significance for performance. Still, it is important to note that our subjects were trained endurance runners, and our outcomes may not accurately reflect the response within the highly-trained or elite endurance runner population.

This work brings developments in the study of running economy by connecting the Functional Movement Screen to metabolic cost. The Functional Movement Screen is an athlete assessment tool growing in popularity and recognition, and therefore an appropriate instrument to analyze. Differently from the original hypothesis, overall, deficits – specifically movement asymmetries - seen in the Functional Movement Screen did not cause an increase in the metabolic cost of running, but rather a decrease. This begs the question, is it better to be asymmetrical with a potentially better running economy, but have an increase in potential injury risk? The Functional Movement Screen is typically paired with chronic interventions that will help the athlete eliminate movement deficiencies, including movement pattern asymmetries, over time. Further studies focusing on the effects of corrective exercise interventions for FMS lower scores and asymmetries on running economy could reveal how endurance running coaches should approach training strategies in response to FMS results.

In conclusion, trained runners who displayed movement asymmetries as determined by the Functional Movement Screen demonstrated lower oxygen uptakes during submaximal running than runners who were symmetrical on the FMS movements. Although movement asymmetries have been linked to higher injury risk, there may be an advantage of lower metabolic cost during running, which may be due to differences in leg stiffness. Although total FMS score and scores specifically on the Hurdle Step movement did not influence running economy, the FMS screen remains a staple of pre-participation screening for athletes of all disciplines.

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APPENDIX

A.

IRB study # 1409198761

INDIANA UNIVERSITY INFORMED CONSENT STATEMENT FOR

Functional movement scores, gait, and running economy

You are invited to participate in a research study that will help determine the effects functional movement deficits have on running mechanics and running economy. You were selected as a possible subject because of your status as a highly trained distance runner. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

Disclaimer: It is possible that after completing the study questionnaires that you will not qualify for the study.

The study is being conducted by Robert F. Chapman, Ph.D. (Principal Investigator), and co-investigators Brianna Blohm, Joshua Freeman, and Carrie Docherty, Ph.D. in the Department of Kinesiology at Indiana University-Bloomington.

STUDY PURPOSE

The purpose of the proposed study is to investigate the relationship between functional movement (e.g. balance, flexibility, range of motion), how you run, and the energy cost associated with running.

NUMBER OF PEOPLE TAKING PART IN THE STUDY:

If you agree to participate, you will be one of approximately 50 subjects who will be participating in this research.

PROCEDURES FOR THE STUDY:

If you agree to be in the study, the following items are included:

An invitation will be extended to visit the Human Performance laboratory once at a previously agreed-upon time. The visit will last approximately 45 minutes.

The testing session includes completion of two written questionnaires, measures of your height and weight, measure of your body composition (fat and lean mass), a Functional Movement Screen, and a running test on a treadmill.

Each of these tests is described below.

Height and weight measures. Height will be measured by asking you to stand against a wall and a device will be lowered until it touches the top of your head. Weight will be measured by having you sit on a chair, which is placed on a scale.

Body composition measures. You will be asked to stand on a scale in bare feet and hold two handles connected to the scale. A small, imperceptible electrical current will pass through your body for about two seconds. The scale will calculate an estimate of the percent of your mass that is lean mass and the percent that is fat mass.

Functional Movement Screen. The Functional Movement Screen consists of seven basic movements or tests which are evaluated by a trained, certified assessor. The seven movements include:

Deep Squat: You will be asked to stand with your feet shoulder width apart, and you will hold a lightweight plastic bar above your head. You will be asked to squat as low as you can and return to standing. You will be asked to do this movement approximately 3-5 times.

Hurdle Step: You will be asked to hold a lightweight plastic bar on your shoulders. You will be asked to step forward over a rubber tubing hurdle set at a height just below your knee, then step back to the starting position. You will be asked to do this movement approximately 3-5 times with both the right and left legs.

In-Line Lunge: You will be asked to stand on a plastic board, one foot approximately two feet in front of the other foot. You will be asked to hold a lightweight plastic bar vertically next to your back, touching the back of your head and the back of your pelvis. While keeping your upper body perpendicular to the ground, you will be asked to bend the back knee and touch it to the plastic board on the ground, then return to standing. You will be asked to do this movement approximately 3-5 times with both the right and left legs.

Shoulder Mobility: You will be asked to hold your arms straight out to the side, make fists with both hands, then complete a movement where you try to touch your fists together behind your back with one fist moving above the shoulder and the other arm below the shoulder. You will be asked to do this movement approximately 3-5 times with both arms, alternating upper and lower arm movements.

Trunk Stability Push Up: You will be asked to assume a push up position on the floor, with arms placed with a 90 degree bend at the elbow, and hands placed on the ground with thumbs even with the ears. In one motion, you will be asked to complete a push up. You will be asked to do this movement approximately 3-5 times

Active Straight Leg Raise: You will be asked to lie on your back on the floor and with legs locked at the knee, raise one leg up as high as you can without bending the knee. You will be asked to do this movement approximately 3-5 times with both the right and left legs.

Rotational Stability: You will be asked to assume a position on the floor on your hands and knees, with both hands and both knees touching a 2x4 that is placed between your hands and legs. You will be asked to raise your left hand and left leg without losing contact with the board with your right hand and knee. You will be asked to do this movement approximately 3-5 times, then you will be asked to complete the same movement with the right hand and right leg.

Running Test. This exercise test will be completed on a treadmill. You will be allowed to warm up on the treadmill for five minutes at any pace you would like to select. A strap will be placed around your chest which will measure your heart rate. You will be asked to complete the treadmill running while breathing through a face mask which covers your nose and mouth. Air will flow into and out of your lungs as you breathe through the face mask. The face mask and heart rate monitor are cleansed in a detergent and antibacterial solution following each use. You will be asked to run 3 repetitions of 4 minutes each. The paces will be at progressively faster speeds which correspond approximately to marathon pace, 10k pace, and 5k pace. A rest period of 3 minutes will follow each 4 minute running stage. At the end of the third stage, you will be asked to continue running at the same pace. The slope of the treadmill will increase slightly every two minutes until you fatigue and need to stop. The goal is for you to run for as long as you can. In most subjects, this occurs after approximately 5-8 minutes of running.

RISKS OF TAKING PART IN THE STUDY:

While in the study, the risks are:

Submaximal and maximal exercise tests of healthy individuals, as described by the American College of Sports Medicine, present little risk to the subject and do not require medical clearance for subjects under the age of 40. Potential risks and/or discomforts can include episodes of temporary light-headedness, chest discomfort, leg cramps, occasional irregular heartbeats, and abnormal blood pressure responses. The risk of heart attack, although minor, (approximately 1 to 2 in 10,000) does exist. One death occurs for roughly every 880,000 man hours of submaximal exercise in apparently healthy individuals. During the test you will be closely monitored for any abnormal changes in heart rate or breathing. You are free to indicate any discomfort and discontinue participation at any time.

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All face masks will be cleaned in detergent and antibacterial solution after each use, minimizing the risk of virus transmission between subjects.

There is a potential risk of loss of confidentiality.

BENEFITS OF TAKING PART IN THE STUDY:

The benefits to participation that are reasonable to expect are information regarding your overall level of fitness, flexibility, balance, and range of motion. Other than this information, you will gain little benefit. All subjects will be provided with feedback concerning their own results and the general findings of the study upon request.

CONFIDENTIALITY

Efforts will be made to keep your personal information confidential. Data will be stored on password protected computers in locked rooms with limited public access. We cannot guarantee absolute confidentiality. Your personal information may be disclosed if required by law. Your identity will be held in confidence in reports in which the study may be published and databases in which results may be stored.

Organizations that may inspect and/or copy your research records for quality assurance and data analysis include groups such as the study investigator and his/her research associates, the IU Institutional Review Board or its designees, and (as allowed by law) state or federal agencies, specifically the Office for Human Research Protections (OHRP) who may need to access the collected medical and/or research data.

PAYMENT

Should you qualify for the study, you will be paid a $20 gift card for completing or attempting to complete the testing. Payment is made via a gift card, which will be given to you at the end of your testing session.

COMPENSATION FOR INJURY

In the event of physical injury resulting from your participation in this research, necessary medical treatment will be provided to you at your own expense. Costs not covered by your health care insurer will be your responsibility. Also, it is your responsibility to determine the extent of your health care coverage. There is no program in place for other monetary compensation for such injuries. However, by signing this form you are not giving up any legal rights or benefits to which you are otherwise entitled.

CONTACTS FOR QUESTIONS OR PROBLEMS

For questions about the study or a research-related injury, contact the researcher Robert Chapman, Ph.D. at (812) 856-2452 or rfchapma@indiana.edu. If you cannot reach the researcher during regular business hours (i.e. 8:00AM-5:00PM), please call the IU Human Subjects Office at (812) 856-4242 or (800) 696-2949.

For questions about your rights as a research participant or to discuss problems, complaints or concerns about a research study, or to obtain information, or offer input, contact the IU Human Subjects Office at (812) 856-4242 or (800) 696-2949.

VOLUNTARY NATURE OF STUDY

Taking part in this study is voluntary. You may choose not to take part or may leave the study at any time. Leaving the study will not result in any penalty or loss of benefits to which you are entitled. Your decision whether or not to participate in this study will not affect your current or future relations with the investigators or Indiana University.

IRB study # 1409198761

Your participation may be terminated by the investigator without regard to your consent in the following circumstances: an abnormal response to exercise testing or an inability to complete the exercise tests.

SUBJECT'S CONSENT

In consideration of all of the above, I give my consent to participate in this research study.

I will be given a copy of this informed consent document to keep for my records. I agree to take part in this study.

Subject’s Printed
Name:____

____
Subject’s Signature: Printed Name of Person Obtaining Consent:

Date:

______________________________ ______________
(must be dated by the subject)

____
Signature of Person Obtaining Consent: ______________________Date:

____
For IRB Office Use ONLY

IRB Approval Date: Feb 2, 2015 Expiration Date: Feb 1, 2017

____
04/24/2013 4

v08/23/2011

B

General Study Questionnaire

Name	**Date**

Do you consider yourself to be a highly endurance trained individual?	**(Circle one) YES NO**
Have you run on a treadmill before?	**(Circle one) YES NO**
Do you feel that you can run comfortably on a treadmill at paces between 5k and marathon pace for four minutes?	**(Circle one) YES NO**
Please list your best running event and the best time you have achieved in the past two years:	**Best event: Best time in last two years:**

Participant Signature	**Date**

C. Modified Physical Activity Readiness Questionnaire (PAR-Q)

Name			**Date**
DOB	**Age**	**Home Phone**	**Work Phone**

Regular exercise is associated with many health benefits, yet any change of activity may increase the risk of injury. Please read each question carefully and answer every question honestly:

Yes	**No**	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
Yes	**No**	**2. Do you feel pain in your chest when you do physical activity?**
Yes	**No**	3. **In the past month, have you had chest pain when you were not doing physical activity?**
Yes	**No**	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
Yes	**No**	**5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?**
Yes	**No**	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
Yes	**No**	**7. Do you know of any other reason you should not do physical activity?**
Yes	**No**	**8. Has your doctor ever told you that you have diabetes?**
Yes	**No**	**9. Has your doctor ever told you that you have high blood pressure?**
Yes	**No**	**10. Has your doctor ever told you that you have high cholesterol?**
Yes	**No**	**11. Has your doctor ever told you that you have high blood sugar?**
Yes	**No**	**12. Do you smoke?**
Yes	**No**	**13. Are you currently inactive?**
Yes	**No**	**14. Do you have a father, brother or son with heart disease before the age of 55 years old or a mother, sister or daughter with heart disease before the age of 65 years old?**

15. Measure height and weight to determine BMI:
Height:________
Weight:________

Participant Signature	**Date**

D. Data Procedures/Checklist

Subject ID ____________ Date ___________

Before Subject Arrives

CO_2 calibrator turned on ☐

Facemask prep ☐

Heart Rate Monitor prep ☐

Environmental Factors ☐

Temp_____ Pbar_______ Humidity_______

Open and SAVE Dasylab ☐

Turn Pneumotach on ☐

After Subject Arrives

Questionnaire/consent ☐

Height and Weight ☐

Height (cm) _______ Weight (kg)_____

BIA ☐

FMS ☐

Calibrate Analyzers ☐

CO_2________ O_2________

Explain test to runner ☐

RE Trials ☐

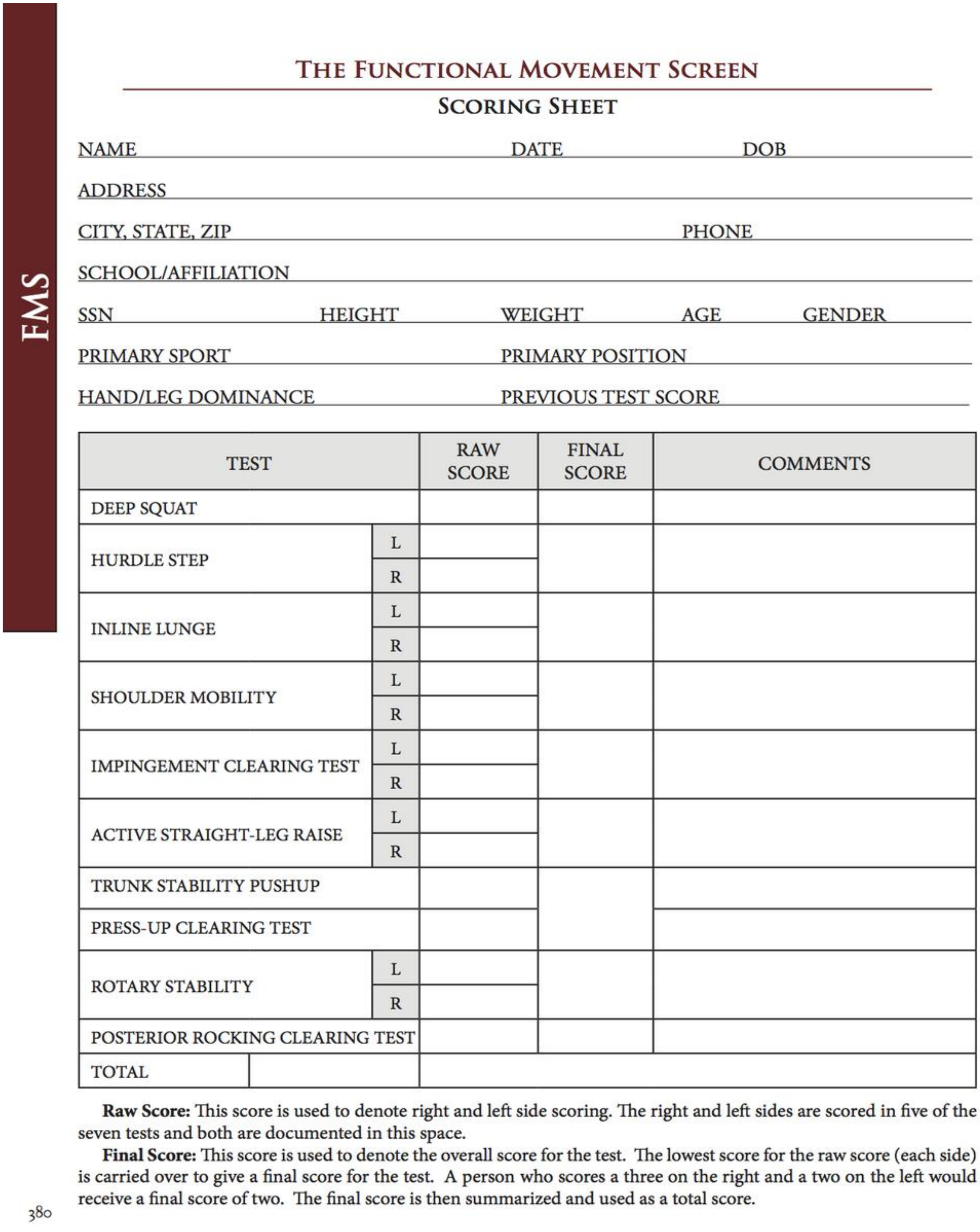
VO_2 Max Test ☐

Open data in Excel ☐

Save data to flashdrive & Box ☐

Clean up- ☐
Collection line, flow control, pneumotach ,monitors, equipment in CIDEX

E.



THE FUNCTIONAL MOVEMENT SCREEN

SCORING SHEET

NAME DATE DOB

ADDRESS

CITY, STATE, ZIP PHONE

SCHOOL/AFFILIATION

SSN HEIGHT WEIGHT AGE GENDER

PRIMARY SPORT PRIMARY POSITION

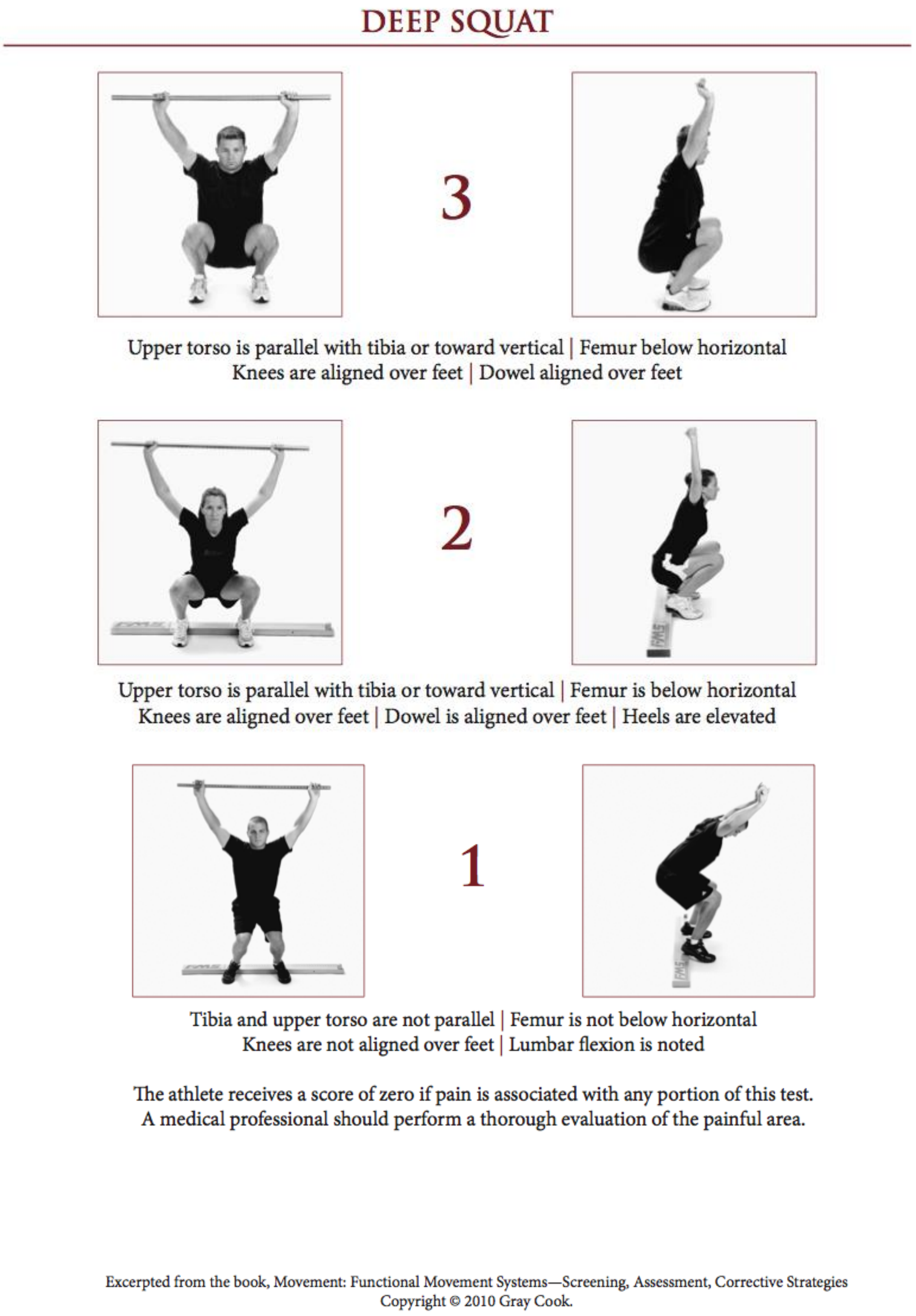
HAND/LEG DOMINANCE PREVIOUS TEST SCORE

TEST		RAW SCORE	FINAL SCORE	COMMENTS
DEEP SQUAT				
HURDLE STEP	L			
	R			
INLINE LUNGE	L			
	R			
SHOULDER MOBILITY	L			
	R			
IMPINGEMENT CLEARING TEST	L			
	R			
ACTIVE STRAIGHT-LEG RAISE	L			
	R			
TRUNK STABILITY PUSHUP				
PRESS-UP CLEARING TEST				
ROTARY STABILITY	L			
	R			
POSTERIOR ROCKING CLEARING TEST				
TOTAL				

Raw Score: This score is used to denote right and left side scoring. The right and left sides are scored in five of the seven tests and both are documented in this space.

Final Score: This score is used to denote the overall score for the test. The lowest score for the raw score (each side) is carried over to give a final score for the test. A person who scores a three on the right and a two on the left would receive a final score of two. The final score is then summarized and used as a total score.

F.



DEEP SQUAT

3

Upper torso is parallel with tibia or toward vertical | Femur below horizontal
Knees are aligned over feet | Dowel aligned over feet

2

Upper torso is parallel with tibia or toward vertical | Femur is below horizontal
Knees are aligned over feet | Dowel is aligned over feet | Heels are elevated

1

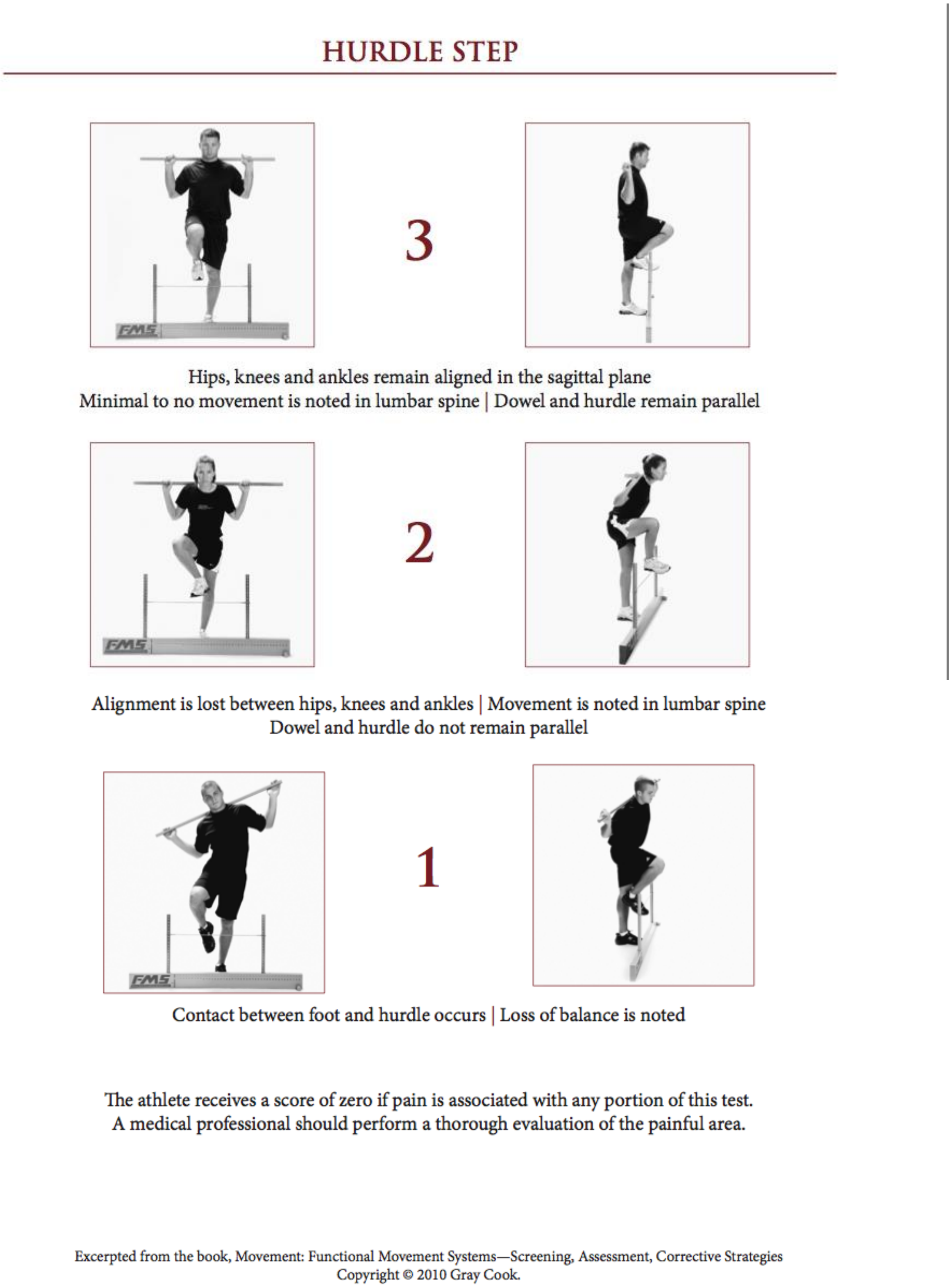
Tibia and upper torso are not parallel | Femur is not below horizontal
Knees are not aligned over feet | Lumbar flexion is noted

The athlete receives a score of zero if pain is associated with any portion of this test.
A medical professional should perform a thorough evaluation of the painful area.

Excerpted from the book, Movement: Functional Movement Systems—Screening, Assessment, Corrective Strategies

G.

H.



HURDLE STEP

3

Hips, knees and ankles remain aligned in the sagittal plane
Minimal to no movement is noted in lumbar spine | Dowel and hurdle remain parallel

2

Alignment is lost between hips, knees and ankles | Movement is noted in lumbar spine
Dowel and hurdle do not remain parallel

1

Contact between foot and hurdle occurs | Loss of balance is noted

The athlete receives a score of zero if pain is associated with any portion of this test.
A medical professional should perform a thorough evaluation of the painful area.

Excerpted from the book, Movement: Functional Movement Systems—Screening, Assessment, Corrective Strategies

H.

I.

INLINE LUNGE

3

Dowel contacts maintained | Dowel remains vertical | No torso movement noted
Dowel and feet remain in sagittal plane | Knee touches board behind heel of front foot

2

Dowel contacts not maintained | Dowel does not remain vertical | Movement noted in torso
Dowel and feet do not remain in sagittal plane | Knee does not touch behind heel of front foot

1

Loss of balance is noted

The athlete receives a score of zero if pain is associated with any portion of this test.
A medical professional should perform a thorough evaluation of the painful area.

I.

SHOULDER MOBILITY

3

Fists are within one hand length

2

Fists are within one-and-a-half hand lengths

1

Fists are not within one and half hand lengths

The athlete will receive a score of zero if pain is associated with any portion of this test. A medical professional should perform a thorough evaluation of the painful area.

CLEARING TEST

Perform this clearing test bilaterally. If the individual does receive a positive score, document both scores for future reference. If there is pain associated with this movement, give a score of zero and perform a thorough evaluation of the shoulder or refer out.

Excerpted from the book, Movement: Functional Movement Systems—Screening, Assessment, Corrective Strategies

J.

ACTIVE STRAIGHT-LEG RAISE

3

Vertical line of the malleolus resides between mid-thigh and ASIS
The non-moving limb remains in neutral position

2

Vertical line of the malleolus resides between mid-thigh and joint line
The non-moving limb remains in neutral position

1

Vertical line of the malleolus resides below joint line
The non-moving limb remains in neutral position

The athlete will receive a score of zero if pain is associated with any portion of this test.
A medical professional should perform a thorough evaluation of the painful area.

Excerpted from the book, Movement: Functional Movement Systems—Screening, Assessment, Corrective Strategies

K.

TRUNK STABILITY PUSHUP

3

The body lifts as a unit with no lag in the spine

Men perform a repetition with thumbs aligned with the top of the head
Women perform a repetition with thumbs aligned with the chin

2

The body lifts as a unit with no lag in the spine
Men perform a repetition with thumbs aligned with the chin | Women with thumbs aligned with the clavicle

1

Men are unable to perform a repetition
with hands aligned with the chin

Women unable with thumbs aligned with the clavicle

The athlete receives a score of zero if pain is associated with any portion of this test.
A medical professional should perform a thorough evaluation of the painful area.

SPINAL EXTENSION CLEARING TEST

Spinal extension is cleared by performing a press-up in the pushup position. If there is pain associated with this motion, give a zero and perform a more thorough evaluation or refer out. If the individual does receive a positive score, document both scores for future reference.

Excerpted from the book, Movement: Functional Movement Systems—Screening, Assessment, Corrective Strategies

L.

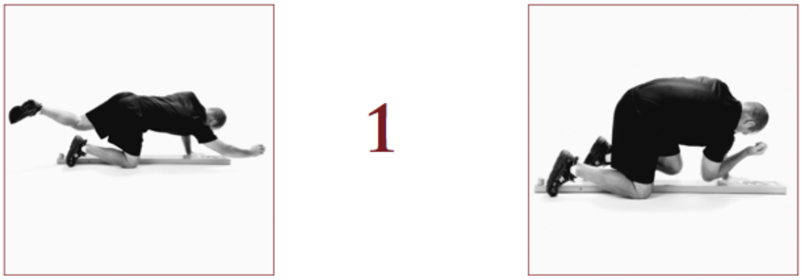
ROTARY STABILITY


3

Performs a correct unilateral repetition


2

Performs a correct diagonal repetition


1

Inability to perform a diagonal repetition

The athlete receives a score of zero if pain is associated with any portion of this test.
A medical professional should perform a thorough evaluation of the painful area.

SPINAL FLEXION CLEARING TEST

Spinal flexion can be cleared by first assuming a quadruped position, then rocking back and touching the buttocks to the heels and the chest to the thighs. The hands should remain in front of the body, reaching out as far as possible. If there is pain associated with this motion, give a zero and perform a more thorough evaluation or refer out. If the individual receives a positive score, document both scores for future reference.

Raw Data

T-Test

Notes

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Group Statistics

	Total Score Group	N	Mean	Std. Deviation	Std. Error Mean
VO2 12	0	2	39.5650	.17678	.12500
	1	22	40.0677	2.74789	.58585
VO2 14	0	2	45.5250	2.17082	1.53500
	1	22	45.5523	3.47775	.74146
VO2 16	0	2	49.32	.424	.300
	1	22	51.89	3.718	.793

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df					
VO2 12	Equal variances assumed	2.797	.109	-.254	22					
	Equal variances not assumed			-.839	21.998					
VO2 14	Equal variances assumed	.827	.373	-.011	22					
	Equal variances not assumed			-.016	1.517					
VO2 16	Equal variances assumed	2.799	.108	-.959	22					
	Equal variances not assumed			-3.037	19.183					

Independent Samples Test

		t-test for Equality of Means				
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
					Lower	
VO2 12	Equal variances assumed	.802	-.50273	1.98299	-4.61520	
	Equal variances not assumed	.410	-.50273	.59904	-1.74507	
VO2 14	Equal variances assumed	.992	-.02727	2.53261	-5.27958	
	Equal variances not assumed	.989	-.02727	1.70470	-10.12301	
VO2 16	Equal variances assumed	.348	-2.574	2.684	-8.140	
	Equal variances not assumed	.007	-2.574	.848	-4.347	

Independent Samples Test

		t-test for Equality of Means
		95% Confidence Interval of the Difference
		Upper
VO2 12	Equal variances assumed	3.60974
	Equal variances not assumed	.73961
VO2 14	Equal variances assumed	5.22504
	Equal variances not assumed	10.06847
VO2 16	Equal variances assumed	2.992
	Equal variances not assumed	-.801

T-Test

Notes

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Group Statistics

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	1	21	39.3048	2.93091	.63958
VO2 14	0	19	47.0942	2.93817	.67406
	1	21	44.9219	3.39207	.74021

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df					
VO2 12	Equal variances assumed	.228	.636	1.615	38					
	Equal variances not assumed			1.620	37.919					
VO2 14	Equal variances assumed	1.042	.314	2.154	38					
	Equal variances not assumed			2.170	37.937					

Independent Samples Test

		t-test for Equality of Means				
					95% Confidence Interval of the Difference	
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	
VO2 12	Equal variances assumed	.115	1.46050	.90424	-.37003	
	Equal variances not assumed	.114	1.46050	.90163	-.36487	
VO2 14	Equal variances assumed	.038	2.17231	1.00849	.13073	
	Equal variances not assumed	.036	2.17231	1.00113	.14550	

Independent Samples Test

	t-test for Equality of Means

		95% Confidence Interval of the Difference
		Upper
VO2 12	Equal variances assumed	3.29103
	Equal variances not assumed	3.28588
VO2 14	Equal variances assumed	4.21389
	Equal variances not assumed	4.19911

T-Test

Notes

Output Created		02-MAY-2015 23:52:46
Comments		
Input	Data	\\Client\H$\Documents\Thesis\Overalldata 5-2-15_1.sav
	Active Dataset	DataSet2
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	50
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST GROUPS=HSGroup(0 1) /MISSING=ANALYSIS /VARIABLES=VO212 VO214 /CRITERIA=CI(.95).
Resources	Processor Time	00:00:00.02
	Elapsed Time	00:00:00.11

Group Statistics

	HS Group	N	Mean	Std. Deviation	Std. Error Mean
VO2 12	0	21	39.7576	3.17217	.69222

	1	19	40.2647	2.66028	.61031
VO2 14	0	21	45.6276	3.31619	.72365
	1	19	46.3142	3.39886	.77975

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df					
VO2 12	Equal variances assumed	.019	.890	-.545	38					
	Equal variances not assumed			-.550	37.800					
VO2 14	Equal variances assumed	.011	.917	-.646	38					
	Equal variances not assumed			-.645	37.394					

Independent Samples Test

	t-test for Equality of Means				
	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	

					Lower	
VO2 12	Equal variances assumed	.589	-.50712	.93113	-2.39210	
	Equal variances not assumed	.586	-.50712	.92285	-2.37566	
VO2 14	Equal variances assumed	.522	-.68659	1.06246	-2.83744	
	Equal variances not assumed	.523	-.68659	1.06381	-2.84130	

Independent Samples Test

		t-test for Equality of Means
		95% Confidence Interval of the Difference
		Upper
VO2 12	Equal variances assumed	1.37787
	Equal variances not assumed	1.36142
VO2 14	Equal variances assumed	1.46425
	Equal variances not assumed	1.46812

T-Test

Notes

Output Created		02-MAY-2015 23:54:51
Comments		
Input	Data	\\Client\H$\Documents\Thesis\Overalldata 5-2-15_1.sav
	Active Dataset	DataSet2
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	50
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.

	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST GROUPS=TotalScoreGroup(0 1) /MISSING=ANALYSIS /VARIABLES=VO212 VO214 /CRITERIA=CI(.95).
Resources	Processor Time	00:00:00.00
	Elapsed Time	00:00:00.09

Group Statistics

	Total Score Group	N	Mean	Std. Deviation	Std. Error Mean
VO2 12	0	3	39.5600	.12530	.07234
	1	37	40.0341	3.03018	.49816
VO2 14	0	3	45.9733	1.72024	.99318
	1	37	45.9522	3.44264	.56597

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df					
VO2 12	Equal variances assumed	3.721	.061	-.268	38					
	Equal variances not assumed			-.942	37.236					

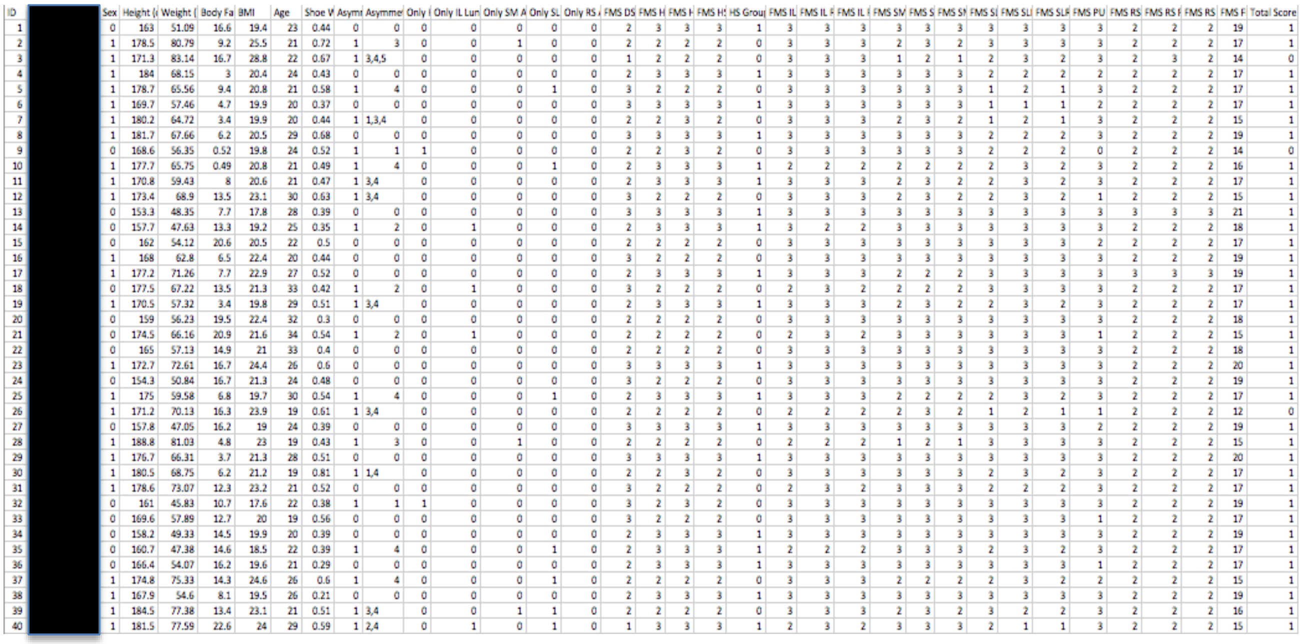
VO2 14	Equal variances assumed	1.338	.255	.010	38					
	Equal variances not assumed			.019	3.489					

Independent Samples Test

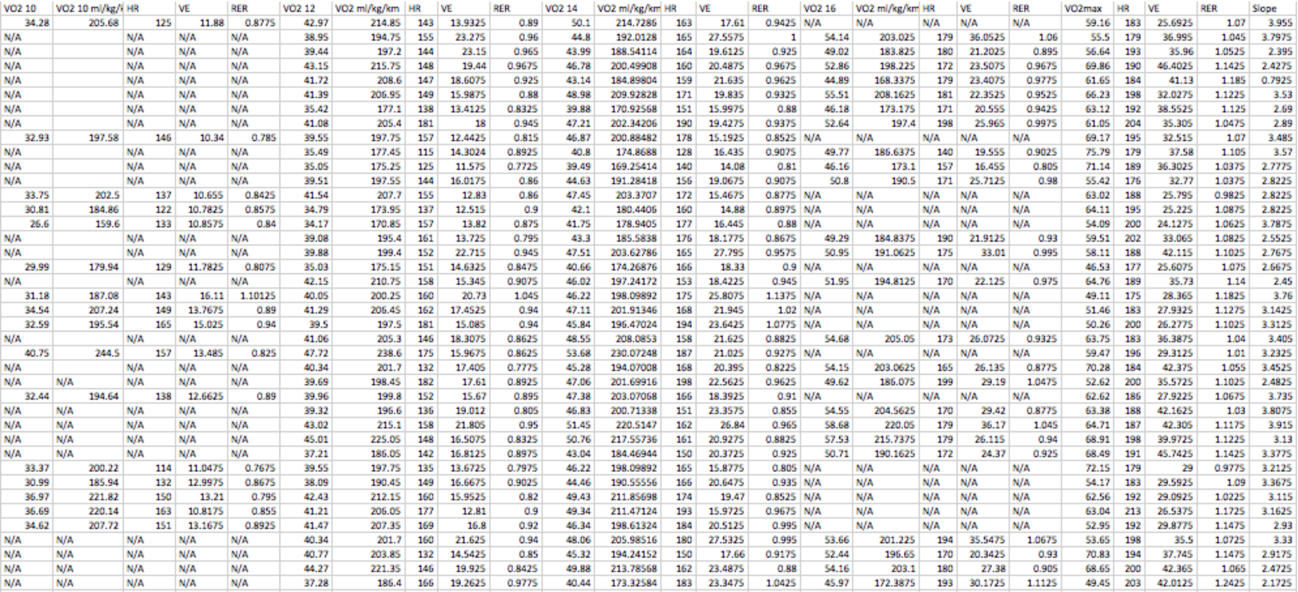
		t-test for Equality of Means				
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	
VO2 12	Equal variances assumed	.790	-.47405	1.77058	-4.05841	
	Equal variances not assumed	.352	-.47405	.50338	-1.49379	
VO2 14	Equal variances assumed	.992	.02117	2.02540	-4.07904	
	Equal variances not assumed	.986	.02117	1.14312	-3.34448	

Independent Samples Test

		t-test for Equality of Means 95% Confidence Interval of the Difference Upper
VO2 12	Equal variances assumed	3.11031
	Equal variances not assumed	.54568
VO2 14	Equal variances assumed	4.12139
	Equal variances not assumed	3.38682



ID	[redacted]	Sex	Height (	Weight (	Body Fa	BMI	Age	Shoe W	Asymm	Asymme	Only I	Only IL Lun	Only SM A	Only SL	Only RS A	FMS DS	FMS H	FMS H	FMS HS	HS Group	FMS IL	FMS IL F	FMS IL I	FMS SM	FMS S	FMS SN	FMS SI	FMS SLI	FMS SLF	FMS PU	FMS RS	FMS RS F	FMS RS	FMS F	Total Score
1	[redacted]	0	163	51.09	16.6	19.4	23	0.44	0	0	0	0	0	0	0	2	3	3	3	1	3	3	3	3	3	3	3	3	3	3	2	2	2	19	1
2	[redacted]	1	178.5	80.79	9.2	25.5	21	0.72	1	3	0	0	1	0	0	2	2	2	2	0	3	3	3	2	3	2	3	3	3	3	2	2	2	17	1
3	[redacted]	1	171.3	83.14	16.7	28.8	22	0.67	1	3,4,5	0	0	0	0	0	1	2	2	2	0	3	3	3	1	2	1	2	3	2	3	2	3	2	14	0
4	[redacted]	1	184	68.15	3	20.4	24	0.43	0	0	0	0	0	0	0	2	3	3	3	1	3	3	3	3	3	3	2	2	2	2	2	2	2	17	1
5	[redacted]	1	178.7	65.56	9.4	20.8	21	0.58	1	4	0	0	0	1	0	3	2	2	2	0	3	3	3	3	3	3	1	2	1	3	2	2	2	17	1
6	[redacted]	1	169.7	57.46	4.7	19.9	20	0.37	0	0	0	0	0	0	0	3	3	3	3	1	3	3	3	3	3	3	1	1	1	2	2	2	2	17	1
7	[redacted]	1	180.2	64.72	3.4	19.9	20	0.44	1	1,3,4	0	0	0	0	0	2	2	3	2	0	3	3	3	2	3	2	1	2	1	3	2	2	2	15	1
8	[redacted]	1	181.7	67.66	6.2	20.5	29	0.68	0	0	0	0	0	0	0	3	3	3	3	1	3	3	3	3	3	3	2	2	2	3	2	2	2	19	1
9	[redacted]	0	168.6	56.35	0.52	19.8	24	0.52	1	1	1	0	0	0	0	2	2	3	2	0	3	3	3	3	3	3	2	2	2	0	2	2	2	14	0
10	[redacted]	1	177.7	65.75	0.49	20.8	21	0.49	1	4	0	0	0	1	0	2	3	3	3	1	2	2	2	2	2	2	2	3	2	3	2	2	2	16	1
11	[redacted]	1	170.8	59.43	8	20.6	21	0.47	1	3,4	0	0	0	0	0	2	3	3	3	1	3	3	3	2	3	2	2	3	2	3	2	2	2	17	1
12	[redacted]	1	173.4	68.9	13.5	23.1	30	0.63	1	3,4	0	0	0	0	0	3	2	2	2	0	3	3	3	2	3	2	2	3	2	1	2	2	2	15	1
13	[redacted]	0	153.3	48.35	7.7	17.8	28	0.39	0	0	0	0	0	0	0	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	21	1
14	[redacted]	0	157.7	47.63	13.3	19.2	25	0.35	1	2	0	1	0	0	0	2	3	3	3	1	3	2	2	3	3	3	3	3	3	3	2	2	2	18	1
15	[redacted]	0	162	54.12	20.6	20.5	22	0.5	0	0	0	0	0	0	0	2	2	2	2	0	3	3	3	3	3	3	3	3	3	2	2	2	2	17	1
16	[redacted]	1	168	62.8	6.5	22.4	20	0.44	0	0	0	0	0	0	0	3	2	2	2	0	3	3	3	3	3	3	3	3	3	3	2	2	2	19	1
17	[redacted]	1	177.2	71.26	7.7	22.9	27	0.52	0	0	0	0	0	0	0	2	3	3	3	1	3	3	3	2	2	2	3	3	3	3	3	3	3	19	1
18	[redacted]	0	177.5	67.22	13.5	21.3	33	0.42	1	2	0	1	0	0	0	3	2	2	2	0	2	3	2	2	2	2	3	3	3	3	2	2	2	17	1
19	[redacted]	1	170.5	57.32	3.4	19.8	29	0.51	1	3,4	0	0	0	0	0	2	3	3	3	1	3	3	3	2	3	2	2	3	2	3	2	2	2	17	1
20	[redacted]	0	159	56.23	19.5	22.4	32	0.3	0	0	0	0	0	0	0	2	2	2	2	0	3	3	3	3	3	3	3	3	3	3	2	2	2	18	1
21	[redacted]	0	174.5	66.16	20.9	21.6	34	0.54	1	2	0	1	0	0	0	2	2	2	2	0	2	3	2	3	3	3	3	3	3	1	2	2	2	15	1
22	[redacted]	0	165	57.13	14.9	21	33	0.4	0	0	0	0	0	0	0	2	2	2	2	0	3	3	3	3	3	3	3	3	3	3	2	2	2	18	1
23	[redacted]	1	172.7	72.61	16.7	24.4	26	0.6	0	0	0	0	0	0	0	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	2	2	2	20	1
24	[redacted]	0	154.3	50.84	16.7	21.3	24	0.48	0	0	0	0	0	0	0	3	2	2	2	0	3	3	3	3	3	3	3	3	3	3	2	2	2	19	1
25	[redacted]	1	175	59.58	6.8	19.7	30	0.54	1	4	0	0	0	1	0	2	3	3	3	1	3	3	3	2	2	2	2	3	2	3	2	2	2	17	1
26	[redacted]	1	171.2	70.13	16.3	23.9	19	0.61	1	3,4	0	0	0	0	0	2	2	2	2	0	2	2	2	2	3	2	1	2	1	1	2	2	2	12	0
27	[redacted]	0	157.8	47.05	16.2	19	24	0.39	0	0	0	0	0	0	0	3	3	3	3	1	3	3	3	3	3	3	3	3	3	2	2	2	2	19	1
28	[redacted]	1	188.8	81.03	4.8	23	19	0.43	1	3	0	0	1	0	0	2	2	2	2	0	2	2	2	1	2	1	3	3	3	3	2	2	2	15	1
29	[redacted]	1	176.7	66.31	3.7	21.3	28	0.51	0	0	0	0	0	0	0	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	2	2	2	20	1
30	[redacted]	1	180.5	68.75	6.2	21.2	19	0.81	1	1,4	0	0	0	0	0	2	2	3	2	0	3	3	3	3	3	3	2	3	2	3	2	2	2	17	1
31	[redacted]	1	178.6	73.07	12.3	23.2	21	0.52	0	0	0	0	0	0	0	3	2	2	2	0	2	3	2	3	3	3	2	2	2	3	2	2	2	17	1
32	[redacted]	0	161	45.83	10.7	17.6	22	0.38	1	1	1	0	0	0	0	3	2	3	2	0	3	3	3	3	3	3	3	3	3	3	2	2	2	19	1
33	[redacted]	0	169.6	57.89	12.7	20	19	0.56	0	0	0	0	0	0	0	3	2	2	2	0	3	3	3	3	3	3	3	3	3	1	2	2	2	17	1
34	[redacted]	0	158.2	49.33	14.5	19.9	20	0.39	0	0	0	0	0	0	0	2	3	3	3	1	3	3	3	3	3	3	3	3	3	3	2	2	2	19	1
35	[redacted]	0	160.7	47.38	14.6	18.5	22	0.39	1	4	0	0	0	1	0	2	3	3	3	1	2	2	2	3	3	3	2	3	2	3	2	2	2	17	1
36	[redacted]	0	166.4	54.07	16.2	19.6	21	0.29	0	0	0	0	0	0	0	2	3	3	3	1	3	3	3	3	3	3	3	3	3	1	2	2	2	17	1
37	[redacted]	1	174.8	75.33	14.3	24.6	26	0.6	1	4	0	0	0	1	0	2	2	2	2	0	3	3	3	2	2	2	2	3	2	2	2	2	2	15	1
38	[redacted]	1	167.9	54.6	8.1	19.5	26	0.21	0	0	0	0	0	0	0	2	3	3	3	1	3	3	3	3	3	3	3	3	3	3	2	2	2	19	1
39	[redacted]	1	184.5	77.38	13.4	23.1	21	0.51	1	3,4	0	0	1	1	0	2	2	2	2	0	3	3	3	2	3	2	3	2	2	3	2	2	2	16	1
40	[redacted]	1	181.5	77.59	22.6	24	29	0.59	1	2,4	0	1	0	1	0	1	3	3	3	1	2	3	2	3	3	3	2	1	1	3	2	2	2	15	1



VO2 10	VO2 10 ml/kg/	HR	VE	RER	VO2 12	VO2 ml/kg/km	HR	VE	RER	VO2 14	VO2 ml/kg/km	HR	VE	RER	VO2 16	VO2 ml/kg/km	HR	VE	RER	VO2max	HR	VE	RER	Slope
34.28	205.68	125	11.88	0.8775	42.97	214.85	143	13.9325	0.89	50.1	214.7286	163	17.61	0.9425	N/A	N/A	N/A	N/A	N/A	59.16	183	25.6925	1.07	3.955
N/A		N/A	N/A	N/A	38.95	194.75	155	23.275	0.96	44.8	192.0128	165	27.5575	1	54.14	203.025	179	36.0525	1.06	55.5	179	36.995	1.045	3.7975
N/A		N/A	N/A	N/A	39.44	197.2	144	23.15	0.965	43.99	188.54114	164	19.6125	0.925	49.02	183.825	180	21.2025	0.895	56.64	193	35.96	1.0525	2.395
N/A		N/A	N/A	N/A	43.15	215.75	148	19.44	0.9675	46.78	200.49908	160	20.4875	0.9675	52.86	198.225	172	23.5075	0.9675	69.86	190	46.4025	1.1425	2.4275
N/A		N/A	N/A	N/A	41.72	208.6	147	18.6075	0.925	43.14	184.89804	159	21.635	0.9625	44.89	168.3375	179	23.4075	0.9775	61.65	184	41.13	1.185	0.7925
N/A		N/A	N/A	N/A	41.39	206.95	149	15.9875	0.88	48.98	209.92828	171	19.835	0.9325	55.51	208.1625	181	22.3525	0.9525	66.23	198	32.0275	1.1225	3.53
N/A		N/A	N/A	N/A	35.42	177.1	138	13.4125	0.8325	39.88	170.92568	151	15.9975	0.88	46.18	173.175	171	20.555	0.9425	63.12	192	38.5525	1.125	2.69
N/A		N/A	N/A	N/A	41.08	205.4	181	18	0.945	47.21	202.34206	190	19.4275	0.9375	52.64	197.4	198	25.965	0.9975	61.05	204	35.305	1.0475	2.89
32.93	197.58	146	10.34	0.785	39.55	197.75	157	12.4425	0.815	46.87	200.88482	178	15.1925	0.8525	N/A	N/A	N/A	N/A	N/A	69.17	195	32.515	1.07	3.485
N/A		N/A	N/A	N/A	35.49	177.45	115	14.3024	0.8925	40.8	174.8688	128	16.435	0.9075	49.77	186.6375	140	19.555	0.9025	75.79	179	37.58	1.105	3.57
N/A		N/A	N/A	N/A	35.05	175.25	125	11.575	0.7725	39.49	169.25414	140	14.08	0.81	46.16	173.1	157	16.455	0.805	71.14	189	36.3025	1.0375	2.7775
N/A		N/A	N/A	N/A	39.51	197.55	144	16.0175	0.86	44.63	191.28418	156	19.0675	0.9075	50.8	190.5	171	25.7125	0.98	55.42	176	32.77	1.0375	2.8225
33.75	202.5	137	10.655	0.8425	41.54	207.7	155	12.83	0.86	47.45	203.3707	172	15.4675	0.8775	N/A	N/A	N/A	N/A	N/A	63.02	188	25.795	0.9825	2.8225
30.81	184.86	122	10.7825	0.8575	34.79	173.95	137	12.515	0.9	42.1	180.4406	160	14.88	0.8975	N/A	N/A	N/A	N/A	N/A	64.11	195	25.225	1.0875	2.8225
26.6	159.6	133	10.8575	0.84	34.17	170.85	157	13.82	0.875	41.75	178.9405	177	16.445	0.88	N/A	N/A	N/A	N/A	N/A	54.09	200	24.1275	1.0625	3.7875
N/A		N/A	N/A	N/A	39.08	195.4	161	13.725	0.795	43.3	185.5838	176	18.1775	0.8675	49.29	184.8375	190	21.9125	0.93	59.51	202	33.065	1.0825	2.5525
N/A		N/A	N/A	N/A	39.88	199.4	152	22.715	0.945	47.51	203.62786	165	27.795	0.9575	50.95	191.0625	175	33.01	0.995	58.11	188	42.115	1.1025	2.7675
29.99	179.94	129	11.7825	0.8075	35.03	175.15	151	14.6325	0.8475	40.66	174.26876	166	18.33	0.9	N/A	N/A	N/A	N/A	N/A	46.53	177	25.6075	1.075	2.6675
N/A		N/A	N/A	N/A	42.15	210.75	158	15.345	0.9075	46.02	197.24172	153	18.4225	0.945	51.95	194.8125	170	22.125	0.975	64.76	189	35.73	1.14	2.45
31.18	187.08	143	16.11	1.10125	40.05	200.25	160	20.73	1.045	46.22	198.09892	175	25.8075	1.1375	N/A	N/A	N/A	N/A	N/A	49.11	175	28.365	1.1825	3.76
34.54	207.24	149	13.7675	0.89	41.29	206.45	162	17.4525	0.94	47.11	201.91346	168	21.945	1.02	N/A	N/A	N/A	N/A	N/A	51.46	183	27.9325	1.1275	3.1425
32.59	195.54	165	15.025	0.94	39.5	197.5	181	15.085	0.94	45.84	196.47024	194	23.6425	1.0775	N/A	N/A	N/A	N/A	N/A	50.26	200	26.2775	1.1025	3.3125
N/A		N/A	N/A	N/A	41.06	205.3	146	18.3075	0.8625	48.55	208.0853	158	21.625	0.8825	54.68	205.05	173	26.0725	0.9325	63.75	183	36.3875	1.04	3.405
40.75	244.5	157	13.485	0.825	47.72	238.6	175	15.9675	0.8625	53.68	230.07248	187	21.025	0.9275	N/A	N/A	N/A	N/A	N/A	59.47	196	29.3125	1.01	3.2325
N/A		N/A	N/A	N/A	40.34	201.7	132	17.405	0.7775	45.28	194.07008	168	20.395	0.8225	54.15	203.0625	165	26.135	0.8775	70.28	184	42.375	1.055	3.4525
N/A	N/A	N/A	N/A	N/A	39.69	198.45	182	17.61	0.8925	47.06	201.69916	198	22.5625	0.9625	49.62	186.075	199	29.19	1.0475	52.62	200	35.5725	1.1025	2.4825
32.44	194.64	138	12.6625	0.89	39.96	199.8	152	15.67	0.895	47.38	203.07068	166	18.3925	0.91	N/A	N/A	N/A	N/A	N/A	62.62	186	27.9225	1.0675	3.735
N/A	N/A	N/A	N/A	N/A	39.32	196.6	136	19.012	0.805	46.83	200.71338	151	23.3575	0.855	54.55	204.5625	170	29.42	0.8775	63.38	188	42.1625	1.03	3.8075
N/A	N/A	N/A	N/A	N/A	43.02	215.1	158	21.805	0.95	51.45	220.5147	162	26.84	0.965	58.68	220.05	179	36.17	1.045	64.71	187	42.305	1.1175	3.915
N/A	N/A	N/A	N/A	N/A	45.01	225.05	148	16.5075	0.8325	50.76	217.55736	161	20.9275	0.8825	57.53	215.7375	179	26.115	0.94	68.91	198	39.9725	1.1225	3.13
N/A	N/A	N/A	N/A	N/A	37.21	186.05	142	16.8125	0.8975	43.04	184.46944	150	20.3725	0.925	50.71	190.1625	172	24.37	0.925	68.49	191	45.7425	1.1425	3.3775
33.37	200.22	114	11.0475	0.7675	39.55	197.75	135	13.6725	0.7975	46.22	198.09892	165	15.8775	0.805	N/A	N/A	N/A	N/A	N/A	72.15	179	29	0.9775	3.2125
30.99	185.94	132	12.9975	0.8675	38.09	190.45	149	16.6675	0.9025	44.46	190.55556	166	20.6475	0.935	N/A	N/A	N/A	N/A	N/A	54.17	183	29.5925	1.09	3.3675
36.97	221.82	150	13.21	0.795	42.43	212.15	160	15.9525	0.82	49.43	211.85698	174	19.47	0.8525	N/A	N/A	N/A	N/A	N/A	62.56	192	29.0925	1.0225	3.115
36.69	220.14	163	10.8175	0.855	41.21	206.05	177	12.81	0.9	49.34	211.47124	193	15.9725	0.9675	N/A	N/A	N/A	N/A	N/A	63.04	213	26.5375	1.1725	3.1625
34.62	207.72	151	13.1675	0.8925	41.47	207.35	169	16.8	0.92	46.34	198.61324	184	20.5125	0.995	N/A	N/A	N/A	N/A	N/A	52.95	192	29.8775	1.1475	2.93
N/A	N/A	N/A	N/A	N/A	40.34	201.7	160	21.625	0.94	48.06	205.98516	180	27.5325	0.995	53.66	201.225	194	35.5475	1.0675	53.65	198	35.5	1.0725	3.33
N/A	N/A	N/A	N/A	N/A	40.77	203.85	132	14.5425	0.85	45.32	194.24152	150	17.66	0.9175	52.44	196.65	170	20.3425	0.93	70.83	194	37.745	1.1475	2.9175
N/A	N/A	N/A	N/A	N/A	44.27	221.35	146	19.925	0.8425	49.88	213.78568	162	23.4875	0.88	54.16	203.1	180	27.38	0.905	68.65	200	42.365	1.065	2.4725
N/A	N/A	N/A	N/A	N/A	37.28	186.4	166	19.2625	0.9775	40.44	173.32584	183	23.3475	1.0425	45.97	172.3875	193	30.1725	1.1125	49.45	203	42.0125	1.2425	2.1725