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FUNCTIONAL MOVEMENT ASSESSMENT AND CHANGE AFTER A PHYSICAL FITNESS TRAINING PROGRAM IN LAW ENFORCEMENT PERSONNEL

A Dissertation in

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ABSTRACT

Law enforcement personnel (LEP) as a population are at an increased risk for development of chronic and acute health conditions. Compared to the general population, higher rates of obesity, diabetes, hypertension, and musculoskeletal injury have been observed in LEP. Evidence suggests that functional movement patterns are linked to injury risk. Thus, assessment of functional movement patterns in this population was critically examined. Four studies examined measures of physical fitness and patterns of functional movement in newly hired deputy sheriffs. The first study evaluated the validity of a commercially available wrist-worn accelerometer device for estimating energy expenditure (EE) due to physical activity, with the goal of adapting the technology for research use in the deputy sheriff population. The device was able to accurately estimate EE during a bout of walking (3.0 mph); however it was not accurate for estimates of energy expenditure during more intense exercise or during habitual daylong wear. Study 2 established measures of inter-rater reliability for the Functional Movement Screen (FMS) within our sports medicine research group. Inter-rater reliability in the sports medicine research group was acceptable for longitudinal study of deputy sheriff trainees. Normative FMS data for this unique population was established in study 3. The results indicated that FMS scoring in deputy sheriff trainees was negatively associated with body mass index and age. Study 4 examined FMS scoring in deputy sheriff trainees before and after a 9-week physical fitness training program. FMS scores significantly improved following the physical fitness program, moving the group average total FMS score above the proposed injury risk threshold. These results provide the framework for future evaluation of injury risk and assessment of functional movement in LEP.

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PREFACE

Deputy sheriff trainees spend 19-weeks in the basic training program at the Justice and Safety Institute (JASI) at the Pennsylvania State University. During this time, they are expected to train for a physical fitness test upon which future employment decisions are based. It is clear, however, that their chosen profession predisposes them to future health concerns; law enforcement officers are more likely than those in the general population to develop cardiovascular disease, diabetes, hypertension, and dyslipidemia. In addition, musculoskeletal injuries incurred on the job are a common occurrence and account for significant healthcare and workers compensation expenses.

The research works found in this dissertation are bound together by the common question: Are we adequately preparing deputy sheriffs for healthful, injury-free careers in law enforcement? If not, can we change the training paradigm to mutually benefit all of the stakeholders involved? The goal in data collection was to gather as much data on the physical activity habits, physical fitness characteristics, and functional movement profiles of the deputy sheriff trainees as possible.

Prior to using an assessment tool, we must examine if the tool is valid in the target population. Assessment tools to estimate physical activity include self-reports via questionnaires, pedometers, accelerometer devices, and GPS devices. In February 2012, Nike introduced the Nike Fuelband+, a wrist-worn tri-axial accelerometer device that is marketed toward physically active individuals. Nike claims it is able to accurately measure caloric expenditure and steps taken when worn on a habitual basis. Given its size and simplicity in design, it was considered an ideal package for physical activity measurement in the deputy sheriff trainee cohort. Study 1 examines the validity of this device for estimating caloric expenditure due to physical activity in adults. This study was co-authored by Alicia M. Montalvo. Each author (RPR and AMM) equally contributed to all phases of study design, recruitment, data collection/analysis, and manuscript writing.

A different type of assessment tool examines patterns of functional movement as an individual performs dynamic multi-limb movements. The Functional Movement Screen (FMS) is emerging as a pre-participation screening tool that data suggest may be able to predict future musculoskeletal injury risk. As the rating of movement patterns is subjective, reliability of the ratings when using the FMS to form conclusions must be considered. Study 2 examines reliability measures associated with FMS scoring among the Penn State Sports Medicine research group, while Study 3 examines normative FMS scores in the deputy sheriff trainee population.

Building on the lessons learned from previous inquiries, the fourth study describes the physical activity, physical fitness, and functional movement characteristics of deputy sheriff trainees prior-to and following nine weeks of structured physical fitness training. Using this information, we can better identify individuals with potential abnormal movement patterns that may lead to injury and reduce the risk of health and injury concerns.

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CHAPTER 1 - BACKGROUND LITERATURE AND THEORHETICAL FRAMEWORK

INTRODUCTION

Over 50 years ago, it was observed that bus drivers in London developed cardiovascular disease (CVD) more frequently than their counterparts who were more physically active while collecting tickets. The notion that one's occupation could affect their health status had never been documented(26). Today, many occupations in the Western world require the employee to remain sedentary for long periods during the workday. Law enforcement is a physiologically and psychologically stressful occupation(13). It combines long periods of sedentary behavior with intermittent bursts of extreme physical exertion and mental stress. As such, law enforcement officers are at-risk for a multitude of chronic health conditions(12, 14, 36). law enforcement personnel are exposed to occupation-specific risks for CVD such as sudden physical exertion, psychological stress, and long work shifts. Consistently higher rates of obesity and cardiovascular disease are observed in law enforcement personnel compared to the general population(12, 37, 46). In addition the occupation-specific risks, conventional risk factors for CVD include obesity, hypertension, hypercholesterolemia, diabetes, tobacco use, and sedentary lifestyle(5). Achieving and maintaining a healthy body mass index (BMI) along with engaging in regular physical activity are necessary for the prevention of chronic illness and injury(27). In addition to co-morbid conditions, elevated BMI is positively associated with higher health care costs citation.

Workplace injury and absenteeism are significant costs for employers. Most law enforcement officers are employed by the public sector funded by state and local taxes. Thus, decreasing law enforcement workplace injury and absenteeism through the mechanism of increasing officer fitness measures and decreasing modifiable risk factors should be considered an important goal. law enforcement recruits often enter training programs with less than adequate levels of physical fitness to meet the minimum fitness standards of the training program and insufficient physical activity levels necessary to maintain healthy BMIs. Examining possible avenues to improve physical fitness and decrease injury risk in law enforcement officers is a worthwhile research pursuit.

The purpose of this plan of research is to collect comprehensive data on deputy sheriff trainees prior to- and following nine weeks of physical training, which includes aerobic, flexibility, and resistance training. Fitness testing will include measures of balance and flexibility, functional movement, cardiovascular fitness, and muscle strength and endurance. These data will provide insight into the physical fitness characteristics at baseline and potential effects of the current fitness-training program for reducing CVD risk, reducing musculoskeletal injury risk, and maintaining a healthy BMI in deputy sheriff trainees. A scarcity of information exists on the physical fitness of law enforcement recruits entering into full time employment. Improving the physical fitness of new law enforcement personnel entering the workforce is important for preventing injury and chronic illnesses, decreasing workplace absenteeism, and decreasing the health care cost burden.

The Pennsylvania State University is home to the Justice and Safety Institute (JASI) formed in 1971 to meet the professional development and training needs of Pennsylvania law enforcement and public safety officers. Each year, three training classes of deputy sheriff trainees enroll in the 19-week basic training program. A compulsory requirement of this training program is nine weeks of physical fitness training and satisfactory completion of the physical fitness standards set forth by the Training and Education Board of the Commonwealth of Pennsylvania, after which there is no further formal physical fitness requirement for the Sheriff Department. In the Commonwealth of Pennsylvania, deputy sheriffs are affirmed officers of the peace, however their role in law enforcement is different than those of police officers and state troopers. Deputy sheriffs are commonly tasked with transporting individuals to and from court hearings, courthouse security, and prison security. They may also serve warrants and perform other ancillary law enforcement tasks. In this capacity, the physical activity associated with the job of deputy sheriff is similar to that of the firefighter profession.

The primary aim of this research is to evaluate, measure, and describe the physical fitness and functional movement characteristics of this population. If deficits in job-related fitness or functional movements can be identified, adjustments to the fitness-training program can potentially be implemented in future training classes. Increasing the physical fitness of deputy sheriffs in the Commonwealth of Pennsylvania may lead to decreased risk for CVD, lower rates of workplace absenteeism, time-loss injury, and health care cost savings(11). It is unclear if law enforcement personnel are at-risk for musculoskeletal injury and chronic illness prior to full-time employment, or if risk factors develop over the course of one's career. Few data exist on the physical fitness levels of new law enforcement personnel other than meeting the physical fitness standards set forth by their hiring department. This study seeks to fill this gap in the literature and contribute to physical fitness and functional movement assessment research by describing this special population prior to beginning full-time employment.

A related aim of this research is to examine the validity of a consumer-oriented tri-axial accelerometer device for the measurement of physical activity and energy expenditure.

Interest in this device came about due to the simplicity in design and potential for application to estimate physical activity in deputy sheriff trainees. The wrist-worn system has been designed with the physically active individual in mind, and appears to be robust enough to withstand the rigors of the physical training program. In addition, it potentially would not interfere with the duties and uniform requirements of law enforcement officers, allowing for long-term wear and measurement of habitual physical activity.

Another related aim is to examine the intra- and inter-rater reliability of functional movement assessment among Penn State athletic training and sports medicine faculty. The Functional Movement Screen (FMS), a subjective evaluation of an individual's pattern of movement, has received increased attention in the literature for assessing dynamic movement in rehabilitation, athletic, and military populations. Establishing inter-rater reliability within our research group broadens the potential breadth of applications for FMS in our research domain(s).

Aims and Hypotheses

Aim 1. Investigate the validity of a consumer oriented tri-axial accelerometer device for the estimation of caloric expenditure due to known exercise bouts and estimation of caloric expenditure due habitual wear.
Hypothesis 1.a Energy expenditure during exercise will be accurately measured by the accelerometer device.
Hypothesis 1.b. Energy expenditure over the course of a day will be accurately measured by the accelerometer device.

Aim 2. Establish measures of intra- and inter-rater reliability within Penn State Sports Medicine research group for Functional Movement Screen scoring.
Hypothesis 2. Intra- and inter-rater reliability of FMS scoring will be acceptable and consistent with previous reliability reports.

Aim 3. Describe the functional movement profiles of deputy sheriff trainees at baseline and at the conclusion of an 9-week physical training program.
Hypothesis 3.a. Baseline functional movement scores will be inversely related to BMI.
Hypothesis 3.b. Baseline functional movement scores will be positively related to measures of physical fitness.
Hypothesis 3.c. Indices of functional movement competency will improve from the baseline to post-test time points.

BACKGROUND LITERATURE AND THEORETICAL FRAMEWORK

Law Enforcement Personnel and Cardiovascular Disease

Cardiovascular disease (CVD) is the leading cause of death in the United States; nearly 600,000 deaths were attributed to CVD in 2010(45). Risk factors for CVD include those that are modifiable such as obesity, diabetes, physical inactivity, tobacco use and altered blood lipid profiles as well as those that cannot be changed such as age, sex, and genetic factors. Strides in reducing CVD in Americans have been made in recent decades as health care and understanding of the disease improves, however the continued high rates of both obesity and diabetes threaten to stall further progress(45).

LE officers are consistently shown to be at higher risk for the development of chronic health conditions than the average American. In epidemiological studies, male law enforcement officers have been observed to have an increased risk of cardiovascular morbidity and mortality(47). In female law enforcement officers, higher than average rates of diabetes are observed(46). law enforcement officers of both sexes are shown to have higher than average rates of overweight and obesity, hypercholesterolemia, and tobacco use than the general population(35, 37, 46, 47).

The perception of job-related stress is a potentially important predictor variable of CVD and related risk factors in law enforcement officers (14). Job-related stressors are a cause for concern as they may exacerbate physiologic conditions (e.g. hypertension) contributing to poor health(9). The stress of being a law enforcement officer and specifically a female law enforcement officer is positively associated with higher rates of overweight and obesity in female law enforcement officers(46). In female officers, stress is commonly perceived as a contributing factor to CVD risk. Female officers perceiving high levels of job-related stress had higher prevalence of overweight and obesity than those who did not.(46) Perceived stress is associated with CVD and risk factors for CVD such as hypertension, hypercholesterolemia, and low physical activity in male officers(35). Interestingly, male officers consider their health status to be “good to excellent” more frequently than males in the general population(35).

The American Heart Association (AHA) has issued seven cardiovascular health metrics in effort to improve CVD risk in the general population: not smoking; being physically active; having normal blood pressure, blood glucose and total cholesterol levels, maintaining a healthy body weight and eating a healthy diet(45). Data suggest that risk of death due to CVD drops dramatically as an individual complies with a greater number of these metrics. Individuals meeting 3 or 4 of the metrics experienced 55% reduction in risk of death due to CVD, while those meeting 5 to 7 metrics decreased their risk by 63% compared to individuals meeting 2 or less of the metrics(1). Thus, to decrease risk of CVD in law enforcement officers, compliance with the cardiovascular health metrics should be thoroughly considered. Two of these cardiovascular health metrics; maintaining a healthy weight and engagement in regular physical activity, are directly related to the physical fitness training aspect of the deputy sheriff training program. Three others: normal blood pressure, blood glucose, and total cholesterol levels are moderated by habitual physical activity(1, 21).

Cardiorespiratory fitness (CRF) is an objective measure of an individual’s ability to uptake and transport oxygen to exercising muscle tissue usually measured by exercise testing and expressed in relation to body mass. CRF appears to be a strong independent predictor of all-cause mortality(21). CRF is also negatively associated with cancer mortality risk in women(10). Similarly, high amounts daily total physical activity, which is positively associated with higher CRF, is negatively associated with all-cause premature death in adults(20). Meaningful increases in CRF are observed with exercise training; 8-10 weeks of endurance training is sufficient to elicit a 25% increase in CRF(17).

Elevated BMI has been linked to a multitude of co-morbid conditions such as hypertension, increased fasting blood glucose, and altered blood lipid profile; all of which are risk factors for the development of CVD(5). BMI is a risk factor for CVD modifiable by routine engagement in physical activity and healthy lifestyle. The *Healthy People 2010* initiative recommends that healthy adults engage in at least 150 minutes per week of moderate intensity physical activity, but less than half of Americans regularly meet that goal(23, 31, 42, 44). Engagement in regular physical activity is necessary for achieving and maintaining a healthy BMI and preventing chronic illnesses, and should be a priority for the duration of a law enforcement officer's career.

Physical Fitness Training Programs for Law Enforcement Officers

Physical fitness has been studied in several emergency responder related populations, however no studies related specifically to deputy sheriffs could be identified. Police officers and full-time firefighters are two professions that share similar patterns of physical activity and work shift length. Meaningful changes in CRF, muscle strength and endurance, flexibility, and body composition after physical training have been observed in both police trainee and pre-employment firefighter cohorts(16, 39). Among elite law enforcement groups such as suburban

SWAT teams, core strength, flexibility, and body composition are found to be in the lower percentiles of average American fitness(34). Combined with the baseline fitness measures from JASI deputy sheriff trainees, it is evident that CRF, flexibility, and weight status are areas for improvement in many cohorts of law enforcement officers. Improvement in these areas will reduce the occurrence of modifiable risk factors for CVD and relative risk for future injury(3, 14). In lieu of objective measurement of CRF, other markers of fitness such as reduction in distance-run times should be considered to examine improvement in CRF.

Injury Prevention

A concern for law enforcement personnel is workplace injury, specifically musculoskeletal injuries. Injuries sustained during job-related law enforcement duties are a significant importance, as they lead to work time-loss and increased health care cost. Deputy sheriffs have been shown to have a high rate of workplace time-loss injuries, with up to 9.2 injuries per 100 full-time employees annually(38). At this rate nearly 17,000 time-loss injures, up to 41% being musculoskeletal injuries, occur annually among deputy sheriffs in the United States(38). Poor balance and flexibility of the lower extremity has been shown to be a predictor of lower extremity injuries (3, 6, 18, 25). These measures can be assessed in the field with tests that measure an individual's functional movement abilities; patterns of movement necessary for normal functioning. Several testing methods have been developed and validated for predicting future injury and identifying deficits in functional movement patterns. Functional movement testing is a worthwhile endeavor, as the literature suggests that it can identify individuals at risk for future injury before it occurs. Armed with this knowledge, allied health professionals may be able to identify at-risk individuals and modify training protocols to correct deficits and avoid injury.

Functional Movement Screen (FMS)

Assessment of functional movements, such as those in the Functional Movement Screen (FMS), can help to isolate deficits in balance, flexibility, and joint mobility and stability(18, 19). The test takes into account principles of biomechanics and motor control, such as the kinetic link principle, joint proprioception, and compensatory strategies to perform patterns of movement.(7, 8) The FMS is a pre-participation screening test of 7 functional movements and 3 associated clearing tests. It is scored subjectively on a scale of 0-3, with 3 being the highest possible score. Collectively, an individual may score a maximum of 21 points on the test indicating no perceived deficit in movement patterns.

Examining the manner in which individuals go about performing functional movements can help clinicians and practitioners identify functional deficits, compensatory movements individuals use to deal with these deficits, and potential corrective actions to these deficits that may reduce the risk of future injury or improve athletic or functional performance. If movement deficits or poor biomechanical strategies persist, emerging data show that these individuals may be at increased risk for sustaining injuries(4, 18, 32). Using traditional static measures of strength and flexibility may not identify potential strength, flexibility, and/or balance deficits (7).

Performance deficits may be a result of a learned response, subconscious way of doing movements (i.e. cognitive programming) or as a result of past injury(7, 8). In each case, an individual has theoretically programmed alternate movement patterns to deal with a musculoskeletal deficit or prior injury, which may predispose this individual to future musculoskeletal injury(7, 8). Both strength and flexibility imbalance as well as previous injury may lead to functional deficits, which can lead to painful movement, further injury, and/or decreased functional performance.(7, 18, 29)

Several criteria must be examined before FMS can be considered as a pre-participation screening tool for use in evaluation of deputy sheriff trainees. Specifically, the FMS must be evaluated for rater-reliability, validity as an assessment tool to predict future injury risk, and normative FMS scoring measures for the population of interest should be established.

Reliability

While FMS scoring is guided by specific criteria, ambiguous situations do arise and are subject to the discretion of the FMS rater. Inter- and intra-rater reliability of FMS scoring has been examined by multiple authors. In general, both intra-rater reliability (test-retest) and inter-rater reliability has been found to be “moderate to excellent” depending on rater FMS training and education in movement and biomechanics(30, 43). Minick *et al.* using weighted kappa measures, found good agreement between 2 novice raters (89.6% agreement) and between 2 expert raters (86.7% agreement). Interestingly, percent agreement was highest when scoring between novice and expert raters was compared (83-100% agreement, depending on movement)(24). Other authors have also found moderate to good levels of inter-rater reliability; intra-class correlation coefficients (ICCs) between .74 and .90 depending on scorer training, with more FMS training usually yielding higher reliability measures.)(24, 41, 43).

Smith *et al*. observed ICCs between 0.81-0.91 for total scoring depending on the FMS experience of the rater(41). ICCs of 0.74-0.99 have been observed for inter-rater reliability in by other authors indicating “good” to “excellent” agreement between raters when rating subjects in person (2, 30, 43). ICCs of inter-rater reliability when the rater is assessing videotaped subjects suggest that good to excellent inter-rater reliability is still retained, but more dependent on rater experience with FMS(2, 15, 24). This finding is consistent across studies utilizing video. Intra-rater reliability has been shown to be acceptable (ICC’s 0.81-0.91) depending on the rater’s experience with FMS testing(15, 41). Overall, FMS has been demonstrated to have acceptable intra- and inter rater reliability as a pre-participation screening tool.

Injury prediction using FMS

Kiesel and colleagues were among the first to relate an FMS score to injury prediction. Among a group of NFL players, they observed higher injury rates (odds ratio = 11.67) in players scoring less than 14-points on the FMS assessment than those scoring 14 or above. In addition, asymmetries in bilateral movements noted during FMS testing predisposed players to twice the risk of being injured during the season than those without movement asymmetry(18, 19). In subsequent studies, a composite score of 14 has been used as the threshold for injury prediction(3). In military recruit training studies, FMS score 14 or less resulted in a four-fold increase in injury risk during Marine basic training periods(22). In another study, Marine officer candidates scored an average of 16.6, however those scoring less than 14 were again found to have a significantly higher risk of lower extremity injury (RR = 1.65). Higher FMS scoring was positively associated with higher measures of physical fitness; pushups, pull-ups, sit-ups, and faster run times(28). Despite emerging evidence supporting an association between FMS scoring and musculoskeletal injury risk, these data are only generalizable to the population studied, and should not be extrapolated beyond that population.

Normative Score Data

Normative, population-specific data for FMS needs to be established. Few studies have examined “normal” scoring that can be generally applied to other populations. Perry and Koehle provided normative data for a non-athletic, non-military population of middle-aged adults. Among adult males and females, exercise participation was positively associated with FMS scoring, while BMI was negatively associated. Younger adults (aged 20-39) scored higher than older adults (65 years or above), 15.08 vs. 12.68 respectively, and females tended to score higher than males(33). Schneiders et al. reported a mean score of 15.7 points for healthy adults aged 18-40 years. No differences in scoring were reported between males and females(40).

More normative data is needed for special populations. Without normative FMS scoring data, the injury risk hypothesis is limited in generalizability.

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CHAPTER 2 - JOURNAL MANUSCRIPT

TITLE: Validity of the Nike Fuelband in estimating energy expenditure during treadmill exercise and habitual wear in healthy adults

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ABSTRACT

Wrist-worn physical activity monitors have become commercially ubiquitous; however, information regarding their accuracy in estimating energy expenditure (EE) is scarce. The purpose of this study was to investigate the validity of the Nike Fuelband in estimating EE during treadmill exercise and during habitual wear. For the treadmill protocol, 18 men and 21 women wore the Fuelband and ActiGraph GT3 accelerometers on the wrist and hip. Indirect calorimetry was used to estimate EE during slow walking (3.0 mph), brisk walking (4.0 mph), jogging (6.0 mph), and brisk walking on an incline (4.0 mph at 7.5% grade). For the habitual protocol, 23 men and 14 women wore the Fuelband and an ActiGraph GT3 on the hip and wrist for 7 days. For the treadmill exercise, estimated EE obtained via indirect calorimetry was not different from that obtained by the Fuelband during slow walking (27.2 v 27.3 kcal). Estimated EE from indirect calorimetry differed significantly from that of the Fuelband during brisk walking (39.4 v 32.9 kcal, $p < 0.001$), jogging (66.2 v 79.3 kcal, $p < 0.001$), and brisk walking on an incline (61.8 v 34.9 kcal, $p = 0.001$). For the habitual activity, daily estimated EE obtained by the ActiGraph GT3 at the hip differed significantly from that obtained by the Fuelband (672.9 v 1063.9 kcal, $p < 0.001$). The Fuelband is valid for estimating EE during slow walking, but not during more intense treadmill exercise or during habitual wear.

INTRODUCTION

Valid measurement of physical activity and energy expenditure in free-living environments provides the foundation for understanding the relationship between habitual physical activity and health outcomes. However, measurement of physical activity in adults presents several challenges. Retrospectively estimating past activity levels is difficult for individuals. Self-reporting physical activity is often biased and results in an overestimation of moderate to vigorous physical activity and underestimation of light intensity activity(1, 3). Objective methods of assessment, such as accelerometers and electronic activity monitors, are now widely available; however, their ability to accurately measure physical activity in diverse populations is unknown(3). Hip-, wrist-, and thigh-worn accelerometer devices rely on activity counts, or total perturbations in the various axes, recorded by device hardware for use in algorithmic formulas. These activity counts are then used to estimate physical activity intensity, which requires development and validation for the population of interest(4).

Accelerometer devices have become the standard for objective measurement of physical activity. Only recently has the technology been incorporated into the consumer fitness product market. New consumer-oriented accelerometer devices tend to be smaller, less-obtrusive, and more cost-effective than research-oriented devices. Limited data on the accuracy of these new devices exists. Proven validity of consumer-oriented devices creates the potential for their use in both the recreational and research domains. Thus, it is important to assess the validity of these devices for measurement of physical activity.

The Nike+ Fuelband is a wrist-worn tri-axial accelerometer device oriented toward physically active individuals who are interested in monitoring their daily activity rate, energy expenditure (EE), and step count. The accelerometer is used to estimate EE, step count, and a proprietary metric called Nike Fuel points, which is a novel method to standardize physical activity among individuals of different body sizes.

The primary purpose of this study was to examine the validity of the Nike+ Fuelband for estimating EE. Two protocols were designed to simulate the conditions under which a physically active individual might utilize the device: one to measure EE over a discrete period of time (acute bouts of exercise) and another to measure EE over the course of a day (habitual wear). Simulation of this behavior was accomplished with one protocol consisting of acute bouts of treadmill exercise and a second protocol consisting of habitual wear during a consecutive seven-day period. Both wear conditions used hip and wrist-worn tri-axial accelerometer devices valid for use with the study population as a reference method. Additionally, indirect calorimetry was used as a reference standard for estimating energy expenditure during treadmill exercise.

METHODS

Two protocols were designed to simulate the conditions under which a physically active individual might utilize the device: one to measure EE over a discrete period of time (acute bouts of exercise) and another to measure EE over the course of a day (habitual wear). Simulation of this behavior was accomplished with one protocol consisting of acute bouts of treadmill exercise and a second protocol consisting of habitual wear during a consecutive seven-day period. Both wear conditions used hip and wrist-worn tri-axial accelerometer devices valid for use with the study population as a reference method. Additionally, indirect calorimetry was used as a reference standard for estimating energy expenditure during treadmill exercise.

Subjects

Individuals were eligible for participation if they were healthy and between the ages of 18-45. Individuals were excluded if they were greater than *low risk* (more than one risk factor for cardiovascular disease) as outlined by the American College of Sports Medicine Risk Screening Stratification guideline(2). Participants were recruited using fliers posted on campus and in-class announcements. Testing occurred over a 4-month period. Participants read and signed an informed consent form that was approved by the institutional review board of the university. Eighteen men (age = 21.8 ± 2.4 yrs., mass = 81.0 ± 14.4 kg, height = 176.6 ± 8.7 cm) and 21 women (age = 20.4 ± 2.1 yrs., mass = 61.6.1 ± 6.5 kg, height = 163.9 ± 5.7 cm) volunteered for participation in the treadmill exercise protocol. Twenty three men (age = 21.9 ± 2.0 yrs., mass = 177.4 ± 8.4 kg, height = 79.5 ± 15.5 cm) and 14 women (age = 21.1 ± 2.7 yrs., mass = 165.5 ± 6.6 kg, height = 65.6 ± 11.2 cm) volunteered for participation in the habitual wear protocol.

Study Procedure

Protocol 1: Treadmill Exercise

The first portion of the experiment focused on determining the validity of the device during treadmill exercise. Participants completed each of the following four conditions: slow walking at 3.0 mph, brisk walking at 4.0 mph, jogging at 6.0 mph, and brisk walking at 4.0 on a 7.5% incline. Conditions were randomized to eliminate order effect. Exercise was preceded by a two-minute warm-up period at self-selected pace that transitioned directly into the first random condition. Each condition lasted six minutes and bouts were separated by a six-minute rest period.

Participants wore a Polar T34 Heart Rate Transmitter (Polar USA, Lake Success, NY) that synchronized with the software for the metabolic cart to allow the researchers to estimate energy expenditure (EE) in the event of an equipment malfunction. Additionally, participants were asked to point to a number on the Borg Rating of Perceived Exertion Scale every two minutes. Participants understood that an RPE of 18 or over would result in the termination of the remainder of the research. No participants reached the threshold during testing.

During exercise on the treadmill (Trackmaster TMX425C, Full Vision Inc., Newton KS), participants wore the Fuelband (Nike, Inc., Beaverton, OR) and an ActiGraph GT3 (Pensacola, FL) on their right wrists and ActiGraph GT3 on their right hips programmed to their height and weight. Energy Expenditure was estimated via indirect calorimetry (ParvoMedics TrueOne 2400 Metabolic System, OUSW 4.3, Sandy, UT). Condition start and stop times were recorded and marked in the software in order to synchronize ActiGraph GT3 data to Fuelband data. The Fuelband was synchronized to an iPhone 4 (Apple Inc., Cupertino, CA) using the Nike+ Fuelband application (Nike Inc., Beaverton, OR) to allow the researchers to record calorie information at the beginning and end of each condition. At the conclusion of the treadmill exercise protocol, data from the ActiGraph GT3s were extracted and filtered using the ActiGraph software (Version 6.5.3, Pensacola FL), which implements the work-energy theorem.[3]

Protocol 2: 7-Day Habitual Wear

The second portion of the experiment focused on the validity of the Fuelband during a seven-day habitual wear period. Participants were instructed to wear a Fuelband and Actigraph GT3 (Pensacola, FL) on their right wrists and an Actigraph GT3 on their right hips programmed to their height and weight during the seven-day period. Though participants logged non-wear time, this data was not used for filtering ActiGraph data as data cannot be filtered via the software provided by the Fuelband. The devices were not worn at night, while swimming, or while bathing. Once returned, the data were extracted from the devices using the ActiGraph software or Nike+ Connect software (Nike Inc., Beaverton, OR). The first and last days of wear were eliminated to account for device pick-up and drop-off, leaving five complete days of wear time data per participant.

Statistical Analysis

Data were analyzed using SPSS Version 21 (SPSS IBM, New York, U.S.A). Accelerometer counts were not used for analysis as counts cannot be extracted from the Fuelband. For all analyses the Greenhouse-Geisser correction was applied when the assumption of sphericity was violated. Where the F-statistic was significant, a Bonferroni post-hoc comparison was used to examine significant differences among main effects. An *a priori* value of $p < 0.05$ was used to determine statistical significance.

Protocol 1: Treadmill exercise

Repeated measures one-way ANOVA was used to find differences among groups with regard to estimated EE during each specified condition. Results from indirect calorimetry, the Fuelband, and the ActiGraph GT3s at the hip and wrist were used as within-subjects factors for comparing estimated EE. Additionally, Pearson Product Moment Correlation Coefficients were calculated to determine the bivariate relations between the Fuelband, the metabolic cart, and the ActiGraph GT3s at the hip and wrist for each condition.

Protocol 2: 7-Day Habitual Wear

Repeated measures two-way ANOVA was used to find differences among groups with regard to estimated EE during a five day period. Results from the Fuelband and the ActiGraph GT3s at the hip and wrist were used as within-subjects factors for comparing estimated EE. Day of wear was used as the between-subjects factor.

RESULTS

Protocol 1: Treadmill exercise

The means of the estimated EE for each device during each condition and corresponding F-statistics are listed in *Table 2.1*. The results of the repeated measures analyses showed that there were significant differences among devices with regard to estimated EE during all treadmill exercise conditions. *Table 2.2* shows Pearson Product Moment Correlation Coefficients between all combinations of the Fuelband, indirect calorimetry, and the ActiGraphs at the hip and wrist for all conditions. Estimated EE from the Fuelband was most highly correlated to measures obtained by indirect calorimetry ($r = 0.907$, $p < 0.001$) and the ActiGraph GT3 ($r = 0.904$, $p < 0.001$) at the wrist during slow walking at 3.0 mph. Correlations between estimated EE from the Fuelband and indirect calorimetry ($r = 0.601$, $p < 0.001$) and the Fuelband and GT3x at the hip ($r = 0.680$, $p < 0.001$) dropped to a moderate strength during brisk walking at 4.0 mph. During jogging at 6.0 mph, estimated EE from the Fuelband was more highly correlated with the measure from indirect calorimetry ($r = 0.859$, $p < 0.001$) than it was with measures from the ActiGraph GT3 at the hip ($r = 0.627$, $p < 0.001$). Estimated EE from the Fuelband was least correlated to measures obtained by both indirect calorimetry ($r = 0.457$, $p = 0.003$) and the ActiGraph GT3 at the hip ($r = 0.389$, $p = 0.013$).

The results of post-hoc comparisons between each device for slow walking at 3.0 mph, shown in *Table 2.3*, demonstrate that differences between the means of estimated EE from the Fuelband and indirect calorimetry ($p = 1.000$), the Fuelband and ActiGraph GT3 at the hip ($p = 0.112$), and indirect calorimetry and the ActiGraph GT3 at the hip ($p = 0.110$) are not statistically significant. *Table 2.4* shows the results of the post-hoc comparisons between each device for brisk walking at 4.0 mph. These results demonstrate that the differences between estimated EE for the Fuelband and indirect calorimetry ($p < 0.001$) and the Fuelband and the ActiGraph GT3 at the hip ($p < 0.001$) were significantly different. The Fuelband underestimated EE by about 6.5 kcal in comparison to indirect calorimetry and by about 8 kcal in comparison to the ActiGraph GT3 at the hip per six-minute bout of brisk walking. Conversely, differences between EE obtained via indirect calorimetry and the ActiGraph GT3 at the hip were not significantly different ($p = 1.000$).

Table 2.5 shows the post-hoc comparisons between each device for jogging at 6.0 mph. Similar to the results from brisk walking, differences between estimated EE from the Fuelband and indirect calorimetry ($p < 0.001$) and the Fuelband and ActiGraph GT3 at the hip ($p < 0.001$) were statistically significant. While the Fuelband underestimated EE during brisk walking, it overestimated EE during jogging. The Fuelband overestimated by about 13.1 kcal when compared to indirect calorimetry and by about 17 kcal when compared to the ActiGraph at the hip per six-minute bout of jogging. Again, differences in EE obtained via indirect calorimetry and the ActiGraph GT3 at the hip were not significant ($p = 0.779$). The results of post-hoc comparisons between each device for brisk walking at 4.0 mph on a 7.5% incline, shown in *Table 2.6*, demonstrate that differences between the means of estimated EE from the Fuelband and indirect calorimetry ($p < 0.001$), the Fuelband and ActiGraph GT3 at the hip ($p < 0.001$), and indirect calorimetry and the ActiGraph GT3 at the hip ($p = 0.002$) are significant. The Fuelband underestimated EE by about 27 kcal compared to indirect calorimetry and by about 8.5 kcal compared to the ActiGraph GT3 at the hip per six-minute bout of brisk walking on an incline. Similarly, the ActiGraph GT3 at the hip also underestimated EE by 18.5 kcal compared to indirect calorimetry per six-minute bout.

Protocol 2: 7-Day Habitual Wear

The means for the estimated EE for each device during habitual wear are listed in *Table 2.7*. The repeated measures analysis revealed that there were significant differences among the measurements obtained by the devices with regard to estimated EE ($F=65.3$, $p<0.001$). Post-hoc comparisons of estimated EE showed that all devices differed significantly from one another

(*Table 2.8*). The post-hoc analysis showed that differences between means of EE obtained from the Fuelband and the ActiGraph GT3 ($p < 0.001$) were statistically significant. The results indicate that the Fuelband overestimated EE by about 384 kcal, or by 45%, compared to the ActiGraph GT3 at the hip per day of habitual wear. There were no differences found among days of wear.

DISCUSSION

This is the first study to systematically evaluate the validity of the Fuelband device for estimation of EE during treadmill exercise and during habitual wear. The results indicated that while the differences between the estimated EE obtained from the Fuelband and indirect calorimetry during slow walking at 3.0 mph were not significant and, thus, may be valid for this activity, the Fuelband is not valid for estimating EE during more intense levels of treadmill exercise. Furthermore, the Fuelband is not valid for estimating EE during habitual wear, as EE was overestimated compared to the previously validated ActiGraph GT3 at the hip(4). In contrast, Kane et al. found that the Nike+ shoe sensor was valid for estimating EE during level running, but not during slow walking(5). However, it is important to note that the Fuelband is sensitive to changes in exercise intensity as mean estimated EE did change with each treadmill condition.

Because the results demonstrated that the Fuelband is valid for estimating EE during slow walking, it is possible that the algorithm used to convert accelerometer counts to EE for the device was created for this specific activity. The Fuelband is intended for habitual use and individuals are not typically participating in moderate to vigorous physical activity during the day; rather, the average individual may be more sedentary, tending to perform activities such as slow walking. This may explain why the Fuelband is not valid at more intense levels of treadmill exercise or during habitual wear. The device tended to underestimate EE during brisk walking at 4.0 mph, but tended to overestimate EE during jogging at 6.0 mph. This may occur as a result of the identification system of intensity levels as classified by Nike via the device. It is possible that the device was programmed to use a low intensity type algorithm for a pre-determined, lower number of accelerometer counts and to use a high intensity type algorithm for a pre-determined, higher number of accelerometer counts.

Neither the Fuelband nor the ActiGraph GT3 at the hip were able to accurately quantify EE during brisk walking at 4.0 mph on a 7.5% incline when compared to indirect calorimetry. This is likely because neither device was able to detect that individuals were walking on an incline and could not perceive an increase in exercise intensity. However, the fact that average EE as measured by the Fuelband changed with the various treadmill exercises indicates that the accelerometer itself is sensitive enough to capture changes in exercise intensity. Thus, it may be of value to Nike to re-evaluate the algorithms used to estimate EE during different levels of exercise intensity. Finally, as expected using the work-energy theorem the differences between EE measured via indirect calorimetry and ActiGraph GT3 at the hip did not differ significantly during slow walking at 3.0 mph, brisk walking at 4.0 mph, and jogging at 6.0 mph, indicating that our experimental design and execution of methods were satisfactory(4).

Other accelerometers are validated for placement at the hip or thigh(3, 4). The Fuelband's placement at the wrist makes it less advantageous for accurately estimating EE. For example, the Fuelband will not register activity during cycling, whereas the ActiGraph GT3 at the hip will. The design of the Fuelband essentially precludes it from being placed at alternative sites. Additionally, the algorithm is likely designed for placement at the wrist and nowhere else. It is our suggestion that Nike consider creating an interactive physical activity monitor to be worn on the hip or thigh rather than the wrist in order to get a better representation of how the body is moving during activity.

Incidentally, many of the participants recruited for the habitual protocol were long distance runners. Results from the treadmill protocol indicate that the Fuelband tends to overestimate EE during jogging. The disproportionate amount of long distance runners enrolled in this study may have resulted in the overestimation of EE during the habitual protocol. Regardless, the Fuelband is intended for use by physically active individuals. However, it may be of use to repeat this research in sedentary individuals seeking to track estimated EE to determine if the Fuelband is valid in this population.

Finally, this research did not account for the thermic effect of food (TEF) or caffeine intake. We did not provide instruction to participants regarding either eating or ingesting caffeine prior to participating in the treadmill protocol. However, bouts were only six minutes in length and estimated EE from indirect calorimetry did not differ from the estimates obtained from the ActiGraph GT3 at the hip during the three expected conditions, indicating that TEF and the effect of caffeine intake were negligible.

Practical Application

The Nike Fuelband offers a unique way to interactively monitor physical activity in individuals. The interface with smart phones and social networking has potentially interesting implications in the field of exercise motivation. However, the device's algorithm for estimating EE from accelerometer counts needs to be adjusted before these implications can be further investigated.

FIGURE LEGENDS AND TABLES

Table 2.1. Means (standard deviations) of estimated energy expenditure (kcal) for each device by condition during treadmill exercise (n=39).

	Condition			
Device	**3.0 mph**	**4.0 mph**	**6.0 mph**	**4.0 mph at 7.5%**
IC	27.2(5.8)	39.4(8.6)	66.2(15.6)	61.8(13.8)
FB	27.3(6.1)	32.9(8.0)	79.3(19.5)	34.9(8.1)
AGH	30.2(12.5)	40.9(13.1)	62.3(18.3)	43.3(14.3)
AGW	23.0(14.2)	26.9(13.5)	30.5(13.2)	28.2(14.4)
	F = 11.8***	F = 51.6***	F = 214.9***	F = 138.5***

*** sig at 0.001

IC = Indirect Calorimetry; FB = Fuelband; AGH = ActiGraph on the hip; AGW = ActiGraph on the wrist

Table 2.2. Correlation matrices for the bivariate relations between devices at each condition (n=39).

3.0 mph				**6.0 mph**			
	IC	FB	AGH		IC	FB	AGH
FB	0.907***	-		FB	0.859***	-	
AGH	0.919***	0.904***	-	AGH	0.567***	0.627***	-
AGW	0.857***	0.863***	0.876***	AGW	0.950***	0.895***	0.656***
4.0 mph				**4.0 mph at 7.5% incline**			
	IC	FB	AGH		IC	FB	AGH
FB	0.601***	-		FB	0.457**	-	
AGH	0.878***	0.680***	-	AGH	0.826***	0.389*	-
AGW	0.879***	0.695***	0.912***	AGW	0.803***	0.381*	0.879***

* sig at 0.05

**sig at 0.01

*** sig at 0.001

IC = Indirect Calorimetry; FB = Fuelband; AGH = ActiGraph on the hip; AGW = ActiGraph on the wrist

Table 2.3. Differences among means of estimated energy expenditure (kcal) during slow walking at 3.0 mph (n=39).

				95% Confidence Interval	
Comparisons	**Difference (%)**	**Standard error**	**Significance**	**Lower**	**Upper**
IC - FB	-0.077(-0.367)	0.411	1.000	-1.222	1.068
IC - AGH	-2.967(-10.453)	1.204	0.110	-6.319	0.385
IC - AGW	4.246(16.733)	1.555	0.057	-0.082	8.575
FB - AGH	-2.89(-10.087)	1.193	0.122	-6.212	0.432
FB - AGW	4.323(17.097)	1.516	0.042*	0.104	8.542
AGH - AGW	7.213(27.068)	1.098	<0.001*	4.157	10.268

IC = Indirect Calorimetry; FB = Fuelband; AGH = ActiGraph on the hip;

AGW = ActiGraph on the wrist

*Denotes statistical significance at p<0.05.

Table 2.4. Differences among means of estimated energy expenditure (kcal) during brisk walking at 4.0 mph (n=39).

Comparisons	**Difference (%)**	**Standard error**	**Significance**	**95% Confidence Interval**	
				Lower	**Upper**
IC - FB	6.487(17.981)	1.187	<0.001*	3.183	9.791
IC - AGH	-1.503(-3.736)	1.11	1.000	-4.591	1.586
IC - AGW	12.508(37.707)	1.156	<0.001*	9.291	15.725
FB - AGH	-7.99(-21.680)	1.547	<0.001*	-12.297	-3.683
FB - AGW	6.021(20.067)	1.571	0.003*	1.649	10.392
AGH - AGW	14.01(41.298)	0.895	<0.000*	11.52	16.501

IC = Indirect Calorimetry; FB = Fuelband; AGH = ActiGraph on the hip; AGW = ActiGraph on the wrist

*Denotes statistical significance at $p<0.05$.

Table 2.5. Differences among means of estimated energy expenditure (kcal) during jogging at 6.0 mph (n=39).

				95% Confidence Interval	
Comparisons	**Difference (%)**	**Standard error**	**Significance**	**Lower**	**Upper**
IC - FB	-13.077(-18.007)	1.61	<0.001*	-17.558	-8.596
IC - AGH	3.949(6.070)	2.55	0.779	-3.149	11.047
IC - AGW	35.703(73.837)	0.823	<0.001*	33.412	37.993
FB - AGH	17.026(24.011)	2.615	<0.001*	9.748	24.304
FB - AGW	48.779(88.889)	1.549	<0.000*	44.467	53.092
AGH - AGW	31.754(68.534)	2.215	<0.000*	25.589	37.919

IC = Indirect Calorimetry; FB = Fuelband; AGH = ActiGraph on the hip;

AGW = ActiGraph on the wrist

*Denotes statistical significance at $p<0.05$.

Table 2.6. Differences among means of estimated energy expenditure (kcal) during incline brisk walking at 4.0 mph (n=39).

Comparisons	**Difference (%)**	**Standard error**	**Significance**
IC - FB	25.949(55.636)	1.992	<0.001*
IC - AGH	18.454(35.205)	1.331	<0.001*
IC - AGW	33.579(74.667)	1.419	<0.001*
FB - AGH	-8.495(-21.483)	2.145	0.002*
FB - AGW	6.631(21.236)	2.169	0.024*
AGH - AGW	15.126(42.238)	1.129	<0.001*

IC = Indirect Calorimetry; FB = Fuelband; AGH = ActiGraph on the hip;
AGW = ActiGraph on the wrist

*Denotes statistical significance at p<0.05.

Table 2.7. Means (st. dev.) of estimated energy expenditure (kcal) for each device during habitual wear (n=37).

FB	1046.303(51.061)
AGH	661.875(38.164)
AGW	1189.59(56.377)
	F = 63.5*
	*sig at 0.001

FB = Fuelband; AGH = ActiGraph on the hip; AGW = ActiGraph on the wrist

Table 2.8. Differences among means of estimated EE during habitual wear (n=37).

Comparisons	Difference (%)	Standard Error	Significance	95% Confidence Interval Lower	95% Confidence Interval Upper
AGH - FB	-384.428(-45.010)	40.965	<0.001*	-483.421	-285.435
AGH - AGW	-527.716(-57.005)	53.565	<0.001*	-657.159	-389.272
FB - AGW	-143.288(-12.817)	47.862	0.009*	-258.949	-27.626

FB = Fuelband; AGH = ActiGraph on the hip; AGW = ActiGraph on the wrist

*Denotes statistical significance at p<0.05.

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CHAPTER 3 - JOURNAL MANUSCRIPT

TITLE: Rater reliability measures of Functional Movement Screen scoring among a clinically oriented sports medicine team

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ABSTRACT

The Functional Movement Screen (FMS) is a pre-participation assessment tool used to identify potential deficits in movement patterns. Raters assess and score individuals as they perform a series of seven standardized movements. Measures of rater reliability must be established to ensure FMS scoring is reliable among a group of raters and within the same rater. The objective of this study was to examine intra- and inter-rater reliability measures for FMS scoring among a group of sports medicine professionals. Six raters scored a video of 15 participants performing the FMS movements. After seven days, the raters viewed the participant video again, randomized for participant order. Measures of inter-rater reliability were highest between raters with previous FMS experience (ICC = 0.822), while reliability at the group level was good (ICC = 0.746). Inter-rater reliability for each movement ranged from poor on the hurdle step (ICC = 0.054) to excellent on straight leg raise (ICC = 0.772) Intra-rater reliability ranged from acceptable to excellent (ICC = 0.547 – 0.990), dependent of rater background and previous experience with FMS. These data show that FMS has high inter- and intra-rater reliability among sports medicine clinicians, but is influenced by rater background and prior FMS experience.

INTRODUCTION

The cause of an injury in athletics can be simple or multi-faceted. While some injuries can be attributed to a single cause, others may be the result of a chain-reaction of interconnected variables. Dysfunctional patterns of movement and compensatory strategies have been identified as a potential cause of injury in athletic populations(4, 5). Deficits observed in patterns of movement can indicate whether a dysfunction is present in the kinetic chain used to produce segment and whole-body movement during sport. Identifying and correcting these movement dysfunctions may reduce future injury risk in athletic populations.

Pre-participation physical assessments are often performed to ensure an individual can safely withstand the rigors of athletic participation. Lacking, however, have been evidence-based assessment methods that are capable of predicting future risk of musculoskeletal injury. One such assessment method, the Functional Movement Screen (FMS), seeks to link movement mechanics to future injury risk by identifying potential movement dysfunction during pre-participation screening.

Seven unique multi-joint movements comprise the FMS test. Each movement is subjectively scored according to pre-defined criteria and given a score of zero to three points, with a total score of 21 points being the highest possible score. In combination, the tests assess whole body balance, flexibility, joint range of motion, and strength(4, 5, 7). Evidence indicates that movement deficit and abnormalities noted during pre-participation screening can be predictive of future musculoskeletal injury(1, 2). A minimum total score of 14 on the FMS has been suggested as the threshold for future injury risk in professional American football players(7). Players scoring below 14 points on the FMS were more likely to suffer a severe injury during the season of play than those scoring greater than 14 points (OR = 11.67). This minimum score has been applied to military recruits and high school and collegiate athletes with similar conclusions(8, 10).

Assigning numerical score values to movement quality, as is done in FMS testing, is a subjective task. Specific scoring criteria for each movement are outlined in the FMS instructional materials; however rating movement in "real time" introduces movement patterns and scenarios with the potential to confound scoring that are not addressed in the instructional literature. Assuming differences in scoring exist among FMS raters, it is worthwhile to determine the reliability of FMS scoring both intra-rater (i.e. within the same rater) and inter-rater (i.e. among a group of raters).

Several authors have examined intra- and inter-rater reliability measures related to FMS scoring. Smith *et al.* observed intra-rater reliability intra-class correlation coefficients (ICC) between 0.87-0.89, and inter-rater ICCs between 0.81-0.91 depending on the FMS experience of the rater(13). ICCs of 0.74-0.99 have been observed for inter-rater reliability in by other authors indicating good to excellent agreement between raters when rating subjects in-person(11, 13, 15).

ICCs of inter-rater reliability when the rater is assessing videotaped subjects suggest that good to excellent inter-rater reliability is still retained, but more dependent on rater experience with FMS(9). Intra-rater reliability for FMS scoring has been reported to have ICCs between 0.76 and 0.92, indicating excellent agreement between ratings(11, 13, 15). Likewise, intra-rater reliability in a study using videotaped subjects has been reported to be 0.372-0.946 depending on rater experience(6).

In order to consistently rate movement quality across a team of allied health professional (e.g. athletic trainers, physical therapists, and physicians), measures of inter- and intra-rater reliability must be established for the team. Thus, the primary aim of this study is to establish FMS intra- and inter-rater reliability measures in a team of clinically oriented sports medicine professionals.

METHODS

Participants

Fifteen healthy young adult participants were recruited (7 males, 8 females, mean age 20.4 ± 0.99 years) to perform the FMS assessment on video. Six sports medicine-affiliated raters were recruited to score the videos. The raters included two dual-credentialed physical therapist/athletic trainers with more than two years of FMS rating experience (group AT EX), two athletic trainers with prior understanding of the FMS scoring standards but no previous rater experience (group AT), and two athletic training students with no previous FMS experience (group ATS). Rater experience is presented in *Figure 1*. Raters were chosen to represent a range of FMS and clinical sports medicine experience levels and reasonably matched within the pair for FMS knowledge and experience.

Procedures

A video clip for each of the seven FMS movements was created that contained standardized verbal and visual instruction for performing each movement for the FMS participants. Due to the audio quality of the video, the standardized verbal instructions were repeated in-person at the time of testing for each participant.

Each participant read and signed an informed consent for prior to participation in any study protocols. All study procedures were reviewed and approved by the Institutional Review Board at the Pennsylvania State University. Tibial tuberosity height and hand length were measured to the nearest 0.25 inch and recorded. The participant performed each of the seven movements (bilaterally when applicable) and associated clearing tests in the order listed on the FMS scoring sheet. Prior to the initiation of each movement, the participant listened to the standardized verbal instructions and viewed a video clip of the movement to be performed. The seven movements were recorded on high-definition digital video (Flip Ultra HD, model U1120) from a distance of approximately 5.0 meters. Views of deep squat, inline lunge, straight leg raise, trunk stability pushup and rotary stability were from a mediolateral view. Hurdle step and shoulder mobility were recorded as viewed anteroposteriorly. Associated clearing tests were performed but not included in the rater video; however any positive clearing tests were noted in the video.

Each rater was provided the same FMS training materials and scoring criteria guidelines. After reviewing these materials, each rater was briefed of the study procedures and any necessary technical clarifications were made. Raters viewed the videos each of the 15 participants and scored the movements as the participant performed the movement. Raters were instructed to view each movement as many times necessary to determine a score for the movement, and record the score on the standardized FMS score sheet. Seven days later, each rater scored the videos of the participants again (test-retest), in a randomized order using the same format and scoring criteria.

Statistical Analysis

All analyses were performed using SPSS version 22 (IBM, Chicago IL). Descriptive statistics were calculated as means with standard deviations for each of the seven movements as well as the total score.

Inter- and intra-rater reliability measures were calculated as intra-class correlation coefficients (ICC). A 2-way mixed, single measures model was used for ICC calculations, as the raters in this study were not necessarily representative of a larger population of similar raters. Based on FMS experience and clinical sports medicine experience, raters were analyzed individually (intra-rater), by pairs based on clinical education and FMS experience, and by the entire cohort (inter-rater). Paired-samples t-tests were used to test for differences in FMS total scores by rater from session 1 to session 2. Statistical significance was set *a priori* at p = 0.05. Qualitative ratings of agreement based on ICC values were set based on previous definition, with agreement being poor for ICC values less than 0.40, fair for values between 0.40 and 0.59, good for values between 0.60 and 0.74, and excellent for values between 0.75 and 1.0(3, 14).

RESULTS

Table 3.1 presents inter-rater reliability by rater pair. The ICCs were highest between the athletic trainer(s) with prior FMS experience (0.822) followed by athletic trainers with no FMS experience (0.786), and athletic training students (0.568). *Table 3.2* presents inter-rater reliability measures for total score and for each of the seven movements among all six raters. Straight leg raise had the highest inter-rater reliability ICC measure (0.772) while hurdle step provided the lowest inter-rater reliability ICC (0.054). *Table 3.3* presents measures of intra-rater reliability by rater. No statistically significant differences were found in total FMS scores by raters between session 1 and session 2. Intra-rater reliability was highest among athletic trainers, irrespective of previous FMS experience (ICCs = 0.797 – 0.990). Intra-rater reliability was lowest in ATS_1 and ATS_2, with ICCs of 0.710 and 0.547, respectively.

DISCUSSION

The results suggest that the FMS assessment has acceptable inter- and intra-rater reliability among sports medicine clinicians and students. In general, inter-rater reliability was highest (ICC = 0.822) among the raters that were highly trained sports medicine clinicians and had previous FMS rater experience. This reliability is classified as "excellent" according to the defined criteria. Inter-rater reliability between the athletic trainer raters without prior FMS experience was "good" (ICC = 0.786). Inter-rater reliability a between the athletic training student raters was "acceptable" (ICC = 0.568).

Inter-rater reliability by each movement is presented in *Table 3.2*. As a group, inter-rater reliability for FMS total score was between "good" and "excellent" (ICC = 0.746). Hurdle step had the lowest inter-rater reliability (ICC = 0.054); straight leg raise (SLR) had the highest inter-rater reliability (ICC = 0.772). This is an interesting finding and may require further exploration. The hurdle step and shoulder mobility movements were both viewed from the anteroposterior aspect in the video, while the other five movements were viewed from the mediolateral aspect. The hurdle step was purposely filmed from an anteroposterior aspect to show hip, knee, and ankle alignment as well as the maintenance of balance throughout the movement. Identifying and tracking all of these factors throughout the hurdle step movement should be emphasized during FMS rater training. Reliability measures among the seven movements are inconsistent in the literature, and future work should address reliability measures specific to each movement(9, 12).

Intra-rater reliability between session 1 and session 2 ranged "excellent (ICC = 0.990) to acceptable (ICC = 0.547)". In general, intra-rater reliability was higher in the AT EX group than the AT group, with the student group (ATS) having the lowest reliability measures. These data indicate that FMS rater experience may influence intra-rater reliability. Gribble *et al.* observed higher FMS intra-rater reliability in more experienced ATs than athletic training students as well(6). ATs with at least 6 months of FMS experience had excellent intra-rater reliability (ICC = 0.946) while athletic training students had poor reliability (ICC = 0.372). Smith and colleagues observed no difference in intra-rater reliability due to FMS experience. The only certified FMS rater in the study was shown to have the lowest reliability measure of the group (ICC = 0.81), which included raters with no prior FMS experience, however all of the intra-rater values reported were classified as "excellent" by these authors(13).

The use of video for FMS ratings needs to be further evaluated. Possible limitations may exist with the use of video that do not exist with in-person ratings. When rating a participant in-person, the rater has the ability to view the movement from different perspectives during the movement. The rater may also view the participant from oblique angles to assess specific criteria during the movement. The use of biomechanical software to track specific anatomical landmarks throughout the movement may allow raters to more uniformly assess and rate FMS movements on video. Examining the biomechanical patterns associated with the FMS movements may also provide deeper understanding to possible movement deficits.

Sports medicine clinicians are uniquely suited to assess functional movement as a pre-participation screening tool. Identifying movement deficits and designing suitable interventions to correct movement deficits may reduce future injury risk. The results of this study suggest that FMS has “good to excellent” intra- and inter-rater reliability for total FMS scoring depending on rater background and FMS experience. FMS appears as though it can be used professionally even with limited experienced, however FMS experience increases rater reliability.

Acknowledgements

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FIGURE LEGENDS AND TABLES

Figure 3.1. Rater background and FMS experience.

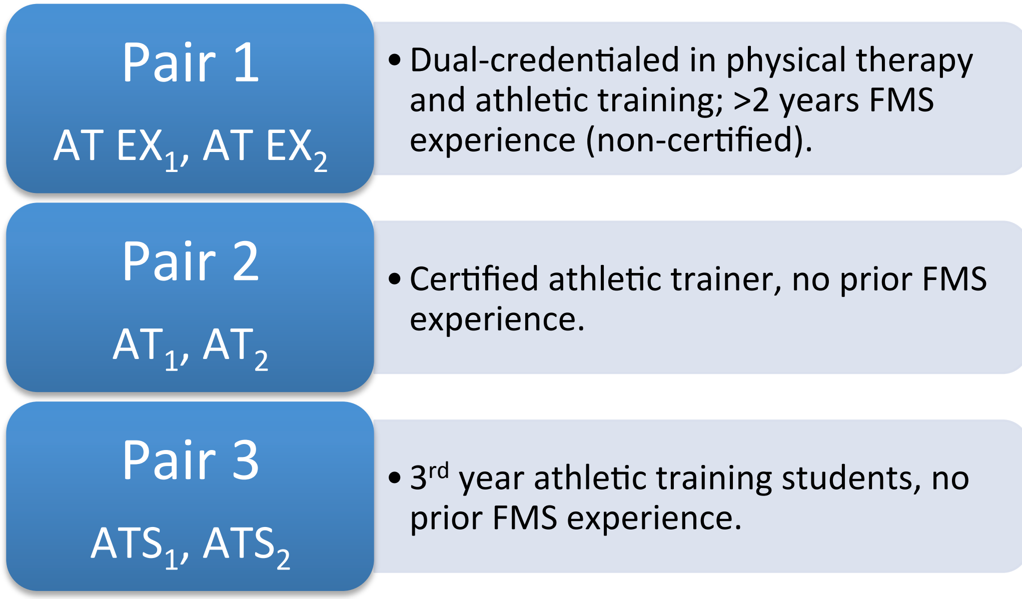

Table 3.1. Inter-rater reliability for total FMS scores by rater pair (n=6).

			95% CI for ICC	
Rater Group	**Mean Score**	**ICC**	**Lower**	**Upper**
AT $EX_{1,2}$	14.76 ± 2.42	0.822	0.550	0.937
$AT_{1,2}$	14.20 ± 2.41	0.786	0.475	0.923
$ATS_{1,2}$	14.83 ± 1.84	0.568	0.098	0.831

Mean score ± standard deviation; ICC = intra-class correlation coefficient

Table 3.2. Inter-rater reliability for FMS total score and by movement among all raters (n=6).

Movement	Mean Score	St. Dev.	ICC	95% CI for ICC	
				Lower	Upper
Total	14.60	2.23	0.746	0.573	0.888
Deep Squat	1.93	0.75	0.671	0.475	0.847
Hurdle Step	1.82	0.51	0.054	-0.061	0.294
Inline Lunge	2.34	0.64	0.338	0.139	0.614
Shoulder Mob.	2.23	0.62	0.729	0.550	0.879
SLR	2.19	0.65	0.772	0.609	0.900
TSP	2.20	0.74	0.642	0.440	0.831
Rotary Stability	1.90	0.56	0.467	0.254	0.718

St. Dev. = standard deviation; ICC = intra-class correlation coefficient; SLR = straight leg raise; TSP = trunk stability pushup

Table 3.3. Intra-rater reliability measures by rater.

Rater	Mean FMS Score Session 1	Mean FMS Score Session 2	ICC	95% CI for ICC	
				Lower	Upper
$ATEX_1$	15.07 ± 2.15	15.33 ± 2.09	0.898	0.723	0.964
$ATEX_2$	14.47 ± 2.70	14.33 ± 2.66	0.962	0.890	0.987
AT_1	14.53 ± 2.48	14.40 ± 2.41	0.990	0.969	0.997
AT_2	13.37 ± 2.39	14.20 ± 2.46	0.797	0.496	0.962
ATS_1	14.60 ± 1.60	15.13 ± 1.77	0.710	0.312	0.888
ATS_2	15.07 ± 2.09	14.07 ± 1.79	0.547	0.068	0.821

FMS total score as mean ± standard deviation; ICC = intra-class correlation coefficient

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CHAPTER 4 - JOURNAL MANUSCRIPT

TITLE: Normative functional movement characteristics among deputy sheriff trainees

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ABSTRACT

The Functional Movement Screen (FMS) is a pre-participation screening tool developed to identify patterns of movement that may increase musculoskeletal injury risk. Lack of population-specific normative data limits its generalizability for use in special populations. This study aims to describe the FMS characteristics of a unique population: deputy sheriff trainees. FMS data were collected for one hundred and nineteen healthy adult deputy sheriff trainees prior to commencement of a physical fitness-training program. Mean FMS score for the entire cohort was 15.02 ± 2.59 points. No differences in mean FMS scores were found between men and women. Mean FMS scores were significantly lower among individuals with body mass index (BMI) values greater than 25.0 and greater than 30.0 than individuals with a BMI less than 24.9, ($p = 0.000$, $p = 0.000$, respectively). Age was negatively associated with FMS scoring, with individuals over 40 years of age scoring lower than younger individuals ($p = 0.041$). These data can assist with identification of atypical scores in future examination of law enforcement trainees.

INTRODUCTION

The Functional Movement Screen (FMS) is a pre-participation assessment tool developed to identify movement pattern dysfunction and asymmetry. The FMS consists of seven multi-joint movements that are scored on an ordinal scale of 0-3 according to defined criteria, with a total maximum score of 21 points. The movements are performed in a standardized order, bilaterally when applicable, and a participant may perform each movement up to three times to achieve the highest score. If pain is associated with any of the movements or associated clearing tests, a score of 0 is assigned to indicate serious dysfunction for that movement(3, 4).

Growing data support a positive association between lower pre-participation FMS scores points and increased risk of future musculoskeletal injury in athletic populations(2, 6, 7). Among American football players, those athletes scoring less than 14 points on a pre-season FMS assessment were more likely (OR = 11.67) to suffer a serious injury during the season of play(6). In addition, the score cut-point of less than 14 points has been shown to predict injury in firefighter recruits during a basic training academy(2). Associations between FMS scores lower than 14 and increased injury risk (RR = 1.91) during training programs have been observed in military populations as well(8). In another study of military recruits, a slower three-mile run time combined with an FMS score of 14 or less increased the predictive value of future injury risk(9). Generalizability of this cut-point to other populations is limited by a lack of normative FMS score data for non-athletic and non-military populations.

Early evidence suggests that FMS scoring in healthy adults may be influenced by age, gender, body mass index (BMI) and participation in exercise(10, 12). Perry and Koehle describe FMS composite score by age, BMI, and gender. Young adults scored higher than older adults, BMI was negatively associated with FMS scoring, and females scored higher than males by group levels. Participation in physical activity was positively associated with FMS scoring(10). Schneiders *et al*. examined FMS scoring in adults aged 18-40 years; no difference in scores was observed between age-matched males and females, and mean FMS score among the entire cohort was 15.7 points(12). Normative FMS scoring measures for specific populations will aid in further exploration of the injury risk prediction model set forth by previous investigators. The aim of this study is to establish normative FMS scoring measures for deputy sheriff recruits prior to beginning a basic training program. To date, no literature exists to describe these measures in this unique population.

METHODS

Participants

One hundred and nineteen deputy sheriff recruits (79% male, 21% female) participated in FMS testing during the first week of the basic training program and prior to the commencement of a compulsory physical fitness-training program. Participant data were combined from six training classes over a two-year period. Age at time of participation ranged from 19-67 years (mean = 29.3 years). Average BMI was 27.7 kg/m^2. All trainees attended the basic training program prior to full-time employment by county sheriff departments. Employment history was diverse, and included individuals with prior military service, individuals changing careers, and recent college graduates. During the training program, two trainees were not available for FMS testing on the day(s) of the assessments, providing a samples size of 117 participants for FMS comparisons.

Procedures

All procedures performed in this study were review by the Institutional Review Board at The Pennsylvania State University. Participants completed several tests as part of the diagnostic fitness assessment prior to commencement of the compulsory fitness-training program. During the first week of a 15-week basic training program, participants completed the FMS as well as other measures of physical fitness (e.g. timed runs, flexibility, and muscular strength and endurance). In addition, participants completed the self-administered International Physical Activity Questionnaire (IPAQ) long-format previously validated for use in adults to estimate habitual participation in physical activity(5).

Participants provided demographic information and completed the FMS and IPAQ surveys on the same day; baseline physical fitness measures were collected on average 3 days later, but not more than 10 days following FMS testing. The two FMS raters used for data collection were sports medicine clinicians, both holding dual-credentials in physical therapy and athletic training. These raters have previously been shown to have good inter-rater reliability (ICC = 0.822) for FMS composite scoring.

Statistical Analysis

All statistical analyses were performed using SPSS Version 22. Descriptive statistics were compiled for participant age, sex, BMI, IPAQ, and composite FMS score. A 2-tailed 2-sample *t*-test was used to test for an effect on FMS scoring due to sex. Linear regression was used to test for significant relationships between FMS composite score and participant age, BMI, and IPAQ in which all assumptions were met. Differences in FMS composite score predicted by BMI and age were assessed by 1-way ANOVAs. Post hoc analysis using Tukey's HSD with 95% simultaneous confidence intervals (SCI) was used to examine differences in BMI group composite scores in which a participant was categorized as normal weight, overweight, or obese according to World Health Organization standards(1). Similarly, participant age was categorized into three groups: 19-29 years of age, 30-39 years of age, and over 40 years of age by ANOVA using post hoc Tukey's HSD with 95% SCI to test for differences in FMS composite score predicted by participant age. Significance level for all tests was set *a priori* at p = 0.05

RESULTS

One hundred and nineteen deputy sheriff trainees participated in the study procedures. Descriptive statistics for age, height, weight, and BMI are presented in *Table 4.1* as total group statistics and by sex. FMS composite scores and physical activity assessed by IPAQ are provided in *Table 4.2*. The IPAQ score represents the total of vigorous activity (8 METs), moderate activity (4 METs) and walking activity (4 METs) over a 7-day period. Two-sample t-test for differences in FMS composite scoring attributed to sex provided a non-significant p-value of 0.619 as shown in *Table 4.3*. Linear regression revealed two statistically significant predictors of

FMS composite score; age (p= 0.028) and BMI (p=0.000) (*Table 4.4*). IPAQ reports of physical activity were not associated with FMS composite score (p=0.108).

Age and BMI were further investigated for influence on FMS composite scores by using one-way ANOVAs with Tukey's honestly significant difference post hoc analyses. BMI categorized into three groups; normal weight, overweight, and obese according to World Health Organization definitions. Tukey's HSD post hoc analysis revealed statistically significant differences in mean composite scores among normal weight, overweight, and obese participants. Lower BMI was positively associated with higher FMS composite scoring as shown in *Table 4.5*. Similarly, one-way ANOVA with Tukey's HSD post hoc analysis indicated a significant difference in FMS composite scores when age was examined. Composite FMS scores for participants 29 years of age and younger were significantly higher than scores for participants older than 40 years of age, but not different from 30-39 years of age as shown in *Table 4.6*.

DISCUSSION

This study is the first to examine normative FMS scoring among deputy sheriff trainees, a unique law-enforcement population. Establishing these measures is an important step needed to begin to form hypotheses about functional movement assessment in this population.

In comparison to previous findings, sex and physical activity levels are not statistically significant predictors of FMS composite scoring(10, 12). An explanation for the lack of significant difference in FMS composite scores may be due to the disproportionate number of males versus females (94 males, 25 females). The sample demographics were limited by the demographic makeup of trainees enrolling in the program. It is plausible that differences in FMS composite scores may become significant if the ratio of males to females were more balanced. Perry and Koehle observed mean FMS composite scores of 14.79 and 15.43 for men and women, respectively, aged 20-39 years(10).

Participant engagement in physical activity (reported as MET*mins*week^{-1}) was not significantly associated with FMS composite scores. In middle-aged adults, engagement in physical activity has been positively associated with higher FMS composite scores(10). It is possible that given a larger sample, a statistically significant relationship would emerge within this population as well. A larger sample may also decrease the relatively large standard deviation around the reported mean IPAQ scores in this study.

Significant associations were observed between FMS composite scores and participant BMI and age. FMS composite scores were lower among those individuals with BMIs in the categories of overweight and obese, 25.0 and 30.0 respectively. Tukey's HSD post hoc analysis revealed significant differences in mean FMS composite scores among all three groups. The group mean for participants classified as obese at the time of testing was 13.242 ± 2.107, below the injury risk cutoff of less than 14 points proposed by Keisel *et al.* (6). This finding indicates that increased adiposity may be a limiting factor in functional movement ability. Proposed explanations for this finding may also include decreased joint mobility, and decreased muscular strength and endurance.

Similarly, a significant difference in FMS composite scores was noted when participants were classified into age groups. Specifically, participants in the 19-29 year old age demographic scored significantly higher than participants over 40 years of age, but not participants between

30-39 years of age. Age may contribute physiologic factors (e.g. increased adiposity, decreased joint range of motion, decreased balance) that affect FMS composite scores. In Perry and Koehle's description of middle-aged adults, differences in FMS composite scores due to age were not evident in participants between 20-49 years of age in either males or females(10). Group mean FMS composite score for participants over 40 years of age was 13.684 ± 2.605, below the injury prediction cutoff score of less than 14 points(6). As a cohort, deputy sheriff trainees scored 15.02 points on average. While above the proposed injury risk value of 14 points, there are still areas for improvement in this population.

A limitation in this study was use of IPAQ to estimate physical activity among participants. Objective measures are preferable to self reports and past recall, however more difficult to collect. An alternative method to the IPAQ should be considered in future studies.

Practical Application

These data are the first to provide normative FMS scores for a unique population of law enforcement trainees. Evidence suggests that law enforcement officers are less healthy than the general population, and due to the nature of the occupation are predisposed to serious musculoskeletal injury risk(11). Assessment of possible functional movement deficits and identifying the presence of compensatory movement strategies is necessary to achieve the goal of musculoskeletal injury prevention. Normative functional movement data for the population of interest is necessary for a means of comparison and application to individual results.

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FIGURE LEGENDS AND TABLES

Table 4.1. Descriptive statistics for participants.

Descriptive Statistic	***N***	***M***	***SD***
Age	**119**	**29.26**	**8.92**
Male	94	29.1	9.13
Female	25	29.96	8.2
Height (cm)	**119**	**179.33**	**36.33**
Male	94	183.02	39.96
Female	25	165.48	6.95
Weight (kg)	**119**	**87.13**	**19.42**
Male	94	91.58	18.76
Female	25	70.4	11.09
Body Mass Index	**119**	**27.87**	**4.47**
Male	94	28.52	4.55
Female	25	25.56	3.18

Table 4.2. FMS and IPAQ scores for participants.

Measure	N	M	SD
FMS Total Score	117	15.02	2.59
IPAQ	81	6157.53	4049.29

FMS = Functional Movement Screen; IPAQ = International Physical Activity Questionnaire. Result is expressed in METs*Min*week^{-1}.

Table 4.3. Total FMS scores by sex.

Sex	N	M	SD	p
Males	92	14.97	2.77	
Females	25	15.2	1.83	0.619

*FMS = Functional Movement Screen; p-value from 2-sample t-test.

Table 4.4. Regression values for age, BMI, and IPAQ on FMS total scores (n=117).

Variable	Standardized B	t	p
Age	-0.211	-2.237	0.028*
BMI	-0.505	-5.339	0.000
IPAQ	-0.155	-1.629	0.108*

BMI = Body Mass Index; IPAQ = International Physical Activity Questionnaire. Result is expressed in METs*Min*week^{-1}; FMS = Functional Movement Screen.

*Denotes statistical significance at $p<0.05$.

Table 4.5. FMS total scores by BMI classification (n=117).

	FMS Score			
BMI Classification	**Mean Score**	**Difference**	**95% SCI (lower, upper)**	**Sig.**
Normal	17.133 ± 1.841	n/a	n/a	n/a
vs. Overweight	14.926 ± 2.394	2.207	(1.029, 3.386)	0.000*
vs. Obese	13.242 ± 2.107	3.891	(2.586, 5.196)	0.000*
Overweight vs. Obese	n/a	1.684	(0.504, 2.827)	0.002*

FMS = Functional Movement Screen; BMI = Body Mass Index; n/a = not applicable.

*Denotes statistical significance at $p<0.05$.

Table 4.6. FMS total scores by age classification (n=117).

	FMS Score		95% SCI	
Age Classification	**Mean Score**	**Difference**	**(lower, upper)**	**Sig.**
Under 29 years	15.286 ± 2.580	n/a	n/a	n/a
vs. 30-39 years	15.238 ± 2.364	0.047	(-1.442, 1.537)	0.997
vs. Over 40 years	13.684 ± 2.605	1.602	(0.052, 3.151)	0.041*
30-39 years vs. Over 40 years	n/a	1.554	(-0.361, 3.469)	0.136

FMS = Functional Movement Screen; n/a = not applicable.

*Denotes statistical significance at p<0.05.

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CHAPTER 5 - JOURNAL MANUSCRIPT

TITLE: Physical fitness training increases functional movement scores in law enforcement trainees

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ABSTRACT

The Functional Movement Screen (FMS) is a pre-participation screening tool developed to identify patterns of movement that may increase musculoskeletal injury risk. The objective of this study is to examine potential change in FMS scoring after a physical fitness training program. Sixty-one deputy sheriff trainees participated in an FMS assessment prior to- and following an 9-week physical fitness training program. Mean total FMS score improved after training (15.29 ± 3.00) compared to baseline (14.44 ± 2.60)($p = 0.032$). Trunk stability pushup was the only FMS movement that increased significantly after training ($p < 0.001$). Measures of physical fitness including vertical leap, 300 meter run time, and 1.5 mile run time improved significantly following the fitness training program ($p < 0.001$). These results indicate that a standardized physical fitness program can increase FMS scoring in a law enforcement population. Increased functional movement ability may reduce work-related injury risk in law enforcement officers.

INTRODUCTION

The Functional Movement Screen (FMS) is a pre-participation assessment tool used to identify dysfunctional patterns of movement. The FMS consists of seven multi-joint movements that are scored on an ordinal scale of 0-3 according to defined criteria, with a total maximum score of 21 points. The movements are performed in a standardized order, bilaterally when applicable, and a participant may perform each movement up to three times to achieve the highest score. If pain is associated with any of the movements or associated clearing tests, a score of 0 is assigned to indicate serious dysfunction for that movement.

Emerging evidence suggests that an individual's performance on the FMS assessment may have predictive value for determining future musculoskeletal injury risk(1, 2, 9, 10). Among American football players, those athletes scoring less than 14 points on a pre=season FMS assessment were more than 11-fold more likely (OR = 11.67) to suffer a serious injury during the season of play(9). In addition, the score cut-point of less than 14 has been shown to predict injury in firefighter recruits during a basic training academy(1). Associations between FMS scores lower than 14 and increased injury risk (RR = 1.91) during training programs have been observed military populations as well(12). In another study of military recruits, a slower three-mile run time combined with an FMS score of 14 or less increased the predictive value of future injury risk(11).

Despite evidence suggesting that the FMS can be used to predict future musculoskeletal injury, it is unclear whether meaningful improvements in FMS scoring can be elicited by an overall increase in physical fitness and conditioning. Peate and colleagues observed a 62% reduction in time loss injuries among firefighters following an intervention to improve core and trunk stabilizing muscle strength; a deficit noted during pre-intervention FMS assessment(13). Among American football players, offseason training reduced bilateral asymmetry in movements noted during FMS assessment(8). Whether meaningful improvements in functional movement occur with physical training requires further investigation.

According to a 2008 census by the United States Department of Justice, there are over 180,000 deputy sheriffs employed in the United States(14). Law enforcement officers are at increased risk for chronic health conditions and musculoskeletal injuries due to the nature of the profession(3-5). Law enforcement officers incur the highest rate of workplace injury among emergency responders (i.e. EMS, firefighters, police officers), with rates as high as 9.2 serious injuries per 100 full-time officers annually(15). Assessment of functional movement in deputy sheriffs may reveal areas for improvement in muscle strength, balance, and flexibility. Improvement in lacking areas may reduce future injury risk. It is unclear if the current physical fitness paradigm employed widely among law enforcement agencies is appropriate for improving functional movement ability in law enforcement agencies. The aim of this study is to assess change in FMS scores prior to and following a standardized physical fitness training program.

METHODS

Participants

Sixty-one deputy sheriff trainees (47 males, 14 females) participated in this study. Data was pooled for three consecutive training classes during the 2012-2013 academic year. All participants were enrolled in a basic training academy to become Pennsylvania deputy sheriffs.

On average, trainees were 30.52 years of age, and entered the training program with a BMI of 28.66. No pre-existing injuries were reported at the time of the baseline assessments. Five participants were lost during the data collection period due to leaving the training program.

Procedures

Participants completed the FMS assessment approximately 3 days prior to and during the last week of a 9-week standardized physical fitness training program. The same 2 raters scored participants across all training classes. The raters were dual-credentialed in physical therapy and athletic training, with previous FMS rater experience. Previous study indicates that inter-rater reliability between the 2 raters was good (ICC = 0.822). Measures of fitness collected included those tested during the Pennsylvania Deputy Sheriffs' Education and Training Board physical fitness test; vertical jump, one-minute sit-up test, 300 meter run, maximum pushup test, and 1.5 mile run. Participants completed physical fitness testing at the commencement of the fitness training program for baseline purposes and at the conclusion for academy record.

The physical fitness training program consisted of 9-weeks of supervised compulsory training including strength training, aerobic training, and instruction in flexibility and self defense. Three two-hour sessions were held per week, totaling 66 hours instructional contact time. All procedures in this study were performed in accordance with the policies of the Institutional Review Board at the Pennsylvania State University.

Statistical Analysis

All statistical analyses were performed using SPSS version 22. Total FMS scores and scores for each of the seven movements prior to and following training were compared by paired samples t-tests with 95% simultaneous confidence intervals (SCI). Differences in fitness measures prior to and following training were tested for by paired samples t-test with 95% SCI. Difference in BMI following training was assessed via paired-samples t-test. Linear regression was used to test for association between changes in fitness measures after training change in FMS scoring. Statistical significance was set at p=0.05 *a priori* for all analyses.

RESULTS

Table 5.1 provides descriptive statistics for age and BMI for all participants, as well as height and weight by gender. Mean height and weight values were provided for males (178.64 ± 6.81cm; 95.19 ± 18.88kg) and females (163.15 ± 5.16cm; 69.25 ± 10.68kg). BMI at the group level was not significantly different from baseline following physical training (29.03 vs. 28.74, respectively, p = 0.673). *Table 5.2* provides descriptive statistics for fitness measures at baseline and post-training. Differences in fitness measures due to training were evaluated in *Table 5.3*, with significant improvement in 300 meter run time, 1.5 mile run time, and vertical leap (p = 0.000). *Table 5.4* presents FMS scores as totals and by movement prior to and following physical training. Prior to the commencement of the training program, 32 of 61 deputy sheriff trainees scored 14 or fewer total points on the FMS assessment. Post-training, 19 of 56 deputy sheriff trainees were at or below the 14-point threshold. Differences in FMS scoring after physical training analyzed by paired-samples t-test are presented in *Table 5.5.*

Total FMS scoring and trunk stability pushup scoring increased significantly after training (p= 0.032 and 0.000, respectively). Linear regression did not indicate statistically significant associations between changes in fitness measures after training and changes in FMS scoring.

DISCUSSION

The significant finding provided by these data is the shift away from the injury risk threshold of 14 or less points after a physical fitness training program. As a group, 32 of 61 deputy sheriff trainees began training with a mean FMS score of 14.4 points, indicating a substantial number of individuals at risk for injury. After training, 19 of 56 deputy sheriff trainees remained at or below the injury risk threshold. These results indicate that physical training does improve functional movement ability.

Group mean composite FMS scores increased significantly after training (14.44 vs. 15.29 points, respectively, p = 0.032). In addition, mean trunk stability pushup (TSP) scores increased significantly after training (2.00 vs. 2.39, respectively, p< 0.001). Significant increase in TSP scoring after physical training is reasonably expected as trainees performed pushups regularly during the training academy. Measures of fitness (300m run, 1.5 mile run, and vertical leap) all significantly improved following training as well.

These results are consistent with those of Kiesel *et al.*, who observed significant improvement in FMS scoring following a standard 7-week offseason training program in professional American football players(8). The authors noted increases in composite FMS scores of 3.0 points on average across participants. Decreases in bilateral movement asymmetry were noted post-training as well(8). In another examination of FMS scoring before and following a physical training program, no significant differences in FMS scores after training were observed among firefighters(6).

Correlations between improvement in FMS scores and specific measures of fitness assessed during this training academy were difficult due to the format of the fitness test administration. Trainees were aware of their required minimum fitness standards, and had little incentive to continue to with the test after the standard was achieved. Maximum pushups and sit-ups in one minute are an example of this scenario. Trainees often stopped the test after they met their required minimum standard so to save energy for the next assessment measure. Thus, 300m run, 1.5 mile run, and vertical leap were chosen as fitness measures as trainees were observed to consistently give maximal effort on the tests. These results indicate that potential improvements in FMS scoring after training are not necessarily predicted by traditional measures of fitness. Further exploration of the factors that influence FMS change during training is necessary.

Frost and colleagues have presented evidence suggesting that FMS scores can be improved by increasing the performers knowledge of the test scoring criteria. FMS scores among firefighters improved by 2.6 points on average when they were made aware of the movement patterns required to achieve a perfect score(7). This finding indicates the need for consistent FMS test protocols to be used among data collection sessions within a study.

Some FMS raters question whether observed movement deficits are the result of a true kinetic chain dysfunction, or a failure of the participant to clearly understand the intent of the movement test based on the verbal FMS script. This consideration was addressed prior to study commencement in the deputy sheriff trainees by providing participants with verbal feedback after each trial to allow them to achieve the highest possible FMS score.

Due to the nature of FMS assessment in this unique population, a true control group for comparison would be difficult to achieve. Examining change in FMS scoring in deputy sheriff trainees after training would benefit from the use of a control cohort. Future studies should address this consideration.

Practical Application

The results of this study indicate that a physical fitness training program can improve functional movement quality in some individuals. Identifying patterns of dysfunctional movement during a pre-participation screening may allow the training program to be tailored to meet an individual's specific needs (e.g. increase hip flexibility, increase shoulder range of motion). Training programs that address the needs of a specific individual may improve functional movement ability and decrease musculoskeletal injury risk.

FIGURE LEGENDS AND TABLES

Table 5.1. Descriptive statistics for participant anthropometrics.

	N	Mean	Std. Dev.
Age	61	30.52	9.70
BMI	61	28.66	4.88
Height (cm)			
Male	47	178.64	6.81
Female	14	163.15	5.16
Weight (kg)			
Male	47	95.19	18.88
Female	14	69.25	10.68

BMI = Body Mass Index.

Table 5.2. Mean values for fitness measures at baseline and post-training (n=61).

	Baseline		**Post-training**	
	Mean	**Std. Dev.**	**Mean**	**St. Dev.**
300 meter run (sec)	57.35	7.87	54.29	6.69
1.5 mile run (mm:ss)	13:04	2:11	12:27	2:00
Vertical leap (in)	19.88	3.43	20.62	3.32

Table 5.3. Paired-samples t-test for difference in fitness measures after physical training (n=61).

	Mean	Std. Dev.	Std. Error Mean	95% CI of the Difference		t	Sig.
				Lower	Upper		
300 meter run (sec)	3.38	3.45	0.47	2.43	4.33	7.13	0.000*
1.5 mile run (sec)	48.48	35.17	4.56	38.52	58.43	9.88	0.000*
Vertical leap (in)	0.88	1.39	0.19	0.49	1.26	4.58	0.000*

*Denotes statistical significance at $p<0.05$.

Table 5.4. Mean FMS scores at baseline and post-physical training.

	Baseline scores			Post-training scores		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
FMS Total	61	14.44	2.60	56	15.29	3.00
Deep Squat	61	2.02	0.56	56	2.04	0.63
Hurdle Step	61	1.87	0.50	56	1.91	0.79
Inline Lunge	61	2.38	0.66	56	2.46	0.66
Shoulder Mobility	61	1.93	0.75	56	2.13	0.74
Straight Leg Raise	61	2.18	0.72	56	2.20	0.77
Trunk Stability Pushup	61	2.00	0.80	56	2.39	0.82
Rotary Stability	61	2.05	0.56	56	2.13	0.74

Table 5.5. Paired-sample t-test for differences in FMS scores after physical training (n=61).

Movement	Mean	Std. Dev.	Std. Error Mean	95% CI of the Difference		t	Sig.
				Lower	Upper		
FMS Total Score	0.79	2.67	0.36	0.07	1.50	2.20	0.032*
Deep Squat	0.04	0.63	0.08	-0.13	0.20	0.42	0.674
Hurdle Step	0.02	0.77	0.10	-0.19	0.23	0.17	0.864
Inline Lunge	0.05	0.84	0.11	-0.17	0.28	0.48	0.635
Shoulder Mobility	0.16	0.68	0.09	-0.02	0.34	1.76	0.083
Straight Leg Raise	-0.02	0.77	0.10	-0.23	0.19	-0.17	0.864
Trunk Stability Pushup	0.43	0.71	0.09	0.24	0.62	4.52	0.000*
Rotary Stability	0.09	0.72	0.10	-0.10	0.28	0.93	0.358

FMS = Functional Movement Screen

*Denotes statistical significance at $p<0.05$.

Table 5.6. Linear regression of change in FMS score (dependent variable) vs. change in fitness measures (independent variable) (n=61).

Independent Variable	Standardized B	t	Sig.
CNG 1.5 mile run	0.049	0.339	0.736
CNG 300m run	-0.210	-1.463	0.150
CNG Vertical leap	0.112	0.778	0.441

FMS = Functional Movement Screen

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CHAPTER 6 - CONCLUSIONS AND FUTURE WORK

Collectively, the results of these studies suggest that there is potential to further this line of inquiry into functional movement assessment and possible injury risk in deputy sheriff trainees and other populations. Work must proceed with caution, however, as conclusions are only generalizable within the population studied. When using any assessment tool, the validity of that tool to measure the intended parameter must first be established. Repeatable findings that a tool consistently measures what it is intended to measure are needed. Next, the reliability of that tool needs to indicate that the data provided are repeatable. Only after an assessment tool is valid and reliable should it be used to make more broad conclusions.

Physical activity and modifiable risk factors for CVD in the deputy sheriff population needs to be examined more closely. Future studies should include objective assessments of physical activity, and more closely evaluate specific risk factors for CVD in this population. Interesting studies could evaluate change in blood lipid levels due to the physical training program or increases in daily step count as measured by pedometers.

We can infer that CRF does improve over the course of the training program, as indicated by improvement in run times, but little else is known about risk for CVD in deputy sheriff trainees, either during the academy or beyond. BMI remains elevated (overweight classification) in this population after physical training. Elevated BMI is a modifiable risk factor for CVD, and future training cycles should explore strategies to help recruits improve their weight status(1).

Several considerations related to FMS assessment need further work to evaluate:

The first lies with assessment administration. As mentioned in study 4, the role verbal instruction plays in FMS scoring is unclear. Frost et al. concluded that FMS scoring could be increased simply by making participants aware of the movement scoring criteria(2). This finding suggests that the verbal script used for FMS assessment does not adequately convey the intent of the movement or its scoring criteria. If a participant does not understand exactly what the rater is looking for, it may be difficult for them to score well on the movement, even in the absence of a true movement deficit.

Next, the link between physical fitness and functional movement needs to be strengthened. McGill and colleagues found poor correlation between functional movement and traditional markers of physical fitness. (i.e. pull-ups, grip strength, hip range of motion)(3). Achieving maximal score on the FMS assessment has less to do with a single measure of strength, flexibility, or aerobic capacity than it does a combination muscular strength, core stability, joint range of motion, flexibility, and balance. The findings by McGill et al. highlight the need for more population-specific normative data(3).

Occupation-specific uniform requirements may play a role in functional movement competency. If a deputy sheriff is required to wear high-laced boots as part of a uniform, should the deputy sheriff wear these boots during FMS assessment? If the boots were to cause a restriction in ankle flexibility, should this be a consideration when assessing functional movement or injury risk? An interesting study would involve having individuals (i.e. deputy sheriffs, firefighters) perform FMS assessments wearing their uniforms and identifying functional movement limitations due to constraints of the uniform.

Finally, while these studies lay the groundwork for future inquiry into functional movement assessment in deputy sheriff trainees, it is still unclear how to alter the training program to elicit across-the-board improvement in functional movement to decrease musculoskeletal injury risk. Conducting a functional movement needs assessment by training class (e.g. identifying poor shoulder mobility on the training class level) and then altering the training protocol to address this needs may be a viable method to decrease musculoskeletal injury risk.

The data presented in this dissertation add to the body of literature on functional movement assessment. More work in more varied populations is needed to understand normative scoring values in diverse populations and the association with musculoskeletal injury risk.

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64. Zimmerman FH. Cardiovascular disease and risk factors in law enforcement personnel: a comprehensive review. *Cardiol Rev* 20: 159-166, 2012.

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EDUCATION

Ph.D.	Kinesiology	Pennsylvania State University	2014
M.S.	Kinesiology	Pennsylvania State University	2010
R.D.	Dietetic Internship	Pennsylvania State University & M.S Hershey Medical Center	2008
B.S.	Nutritional Science	Pennsylvania State University	2007

PUBLICATIONS

Montalvo AM, **Rosendale RP**, Buckley WE, Elavsky S. Validity of the Nike Fuelband+ in estimating energy expenditure during treadmill exercise and habitual wear in healthy adults. In review.

Rosendale RP, Bartok CJ. Evaluation of air-displacement plethysmography for the measurement of body composition in 6-48 month old children. Pediatr Res. 2012 Mar;71(3):299-304

Rosendale RP, Bartok CJ. Letter to the Editor – Invited Response to Demerath and Fields. Pediatr Res. 2012 Sep;72(3):330-331

PROFESSIONAL PRESENTATIONS

Oral Presentations
"FMS Profiles of Law-enforcement Trainees Before and After Physical Conditioning." AAHPERD 2013 National Convention, Charlotte NC, April 2013.
"Body Composition Assessment in Children: What Are Our Options?" Noll Laboratory Colloquium, The Pennsylvania State University, April 2010

Poster Presentations
Rosendale RP, Montalvo AM, Buckley WE, Elavsky S. Nike Fuelband+ is not valid for estimating caloric expenditure in healthy adults during treadmill exercise or during habitual wear. The Graduate School Exhibition, The Pennsylvania State University, March 2013.
Rosendale RP, Bartok CJ. Feasibility of air-displacement plethysmography in children. The Obesity Society 2009 Annual Meeting, October 2009.

SERVICE

Academic Service
Judge, Undergraduate Research Exhibition, Pennsylvania State University, 2009-present

Service to the Community
Volunteer, Kicks 4 Kids Youth Soccer Tournaments, 2012-present.
Youth Mentor, Centre County Youth Services Bureau, 2006-2008.

PROFESSIONAL MEMBERSHIPS

American College of Sports Medicine (2010-present)
Academy of Nutrition and Dietetics (formerly the American Dietetic Association, 2007-present)
Pennsylvania Dietetic Association (2007-present)
American Alliance for Health, Physical Education, Recreation and Dance (2011-present)

AWARDS

College of Health and Human Development Graduate Student Research Endowment Award, 2010
Quentin Wood Educational Excellence Scholarship, 2004