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Influence of a Corrective Exercise Training Program on Measures of Functional Movement Among Active-Duty Firefighters

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INFLUENCE OF A CORRECTIVE EXERCISE TRAINING PROGRAM ON MEASURES OF FUNCTIONAL MOVEMENT AMONG ACTIVE-DUTY FIREFIGHTERS

by

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ABSTRACT

INFLUENCE OF A CORRECTIVE EXERCISE TRAINING PROGRAM ON MEASURES OF FUNCTIONAL MOVEMENT AMONG ACTIVE-DUTY FIREFIGHTERS

by

David J. Cornell

The University of Wisconsin – Milwaukee, 2016
Under the Supervision of Professor Kyle T. Ebersole, Ph.D., LAT

Introduction: Previous research suggests that functional movement quality is related to musculoskeletal injury (MSKI) risk, as well as measures of health and fitness, among the firefighter population. Therefore, if a corrective exercise program could elicit improvements in functional movement quality among firefighters, it may be possible to concomitantly improve health and fitness, as well as decrease MSKI risk, among this cohort population of tactical athletes. **Methods:** Accordingly, 51 active-duty firefighters were recruited to participate in the pre-intervention (Phase 1) and intervention (Phase 2) portions of the current study. Phase 1 examined the relationship between two different functional movement assessments among active-duty firefighters (N = 49): the Functional Movement Screen (FMS) and the Movement Efficiency (ME) Test associated with the Fusionetics Human Performance System. Phase 2 examined the influence of a four-week corrective exercise program aimed at improving functional movement quality on measures of functional movement, as well as measures of health and fitness, among active-duty firefighters (N = 44). Participants were placed into either the Corrective Exercise Program (CEP) group (n = 22) or the Control (CON) group (n = 22) in a counterbalanced fashion, based on their initial quality of functional movement. **Results:** The

four-week corrective exercise programming created by the Fusionetics Human Performance System did not elicit significant improvements in functional movement quality or measures of health and fitness among active-duty firefighters. As such, a short-term corrective exercise program aim at improving functional movement quality did not significantly decrease the theoretical risk of future MSKI in this cohort population. However, exploratory analyses suggest that a lack of supervision by qualified individuals may have influenced the efficacy of the corrective exercise programming. Finally, results of the current study suggest that even though a significant relationship was identified between these two assessments of functional movement quality, the ME Test may lack criterion-reference validity in relation to the FMS among active-duty firefighters. **Conclusions:** Future research should examine the potential influence of supervised and non-supervised corrective exercise training on functional movement quality and the influence of various external factors on these commonly utilized assessments of functional movement within the firefighter population.

To the tactical athletes serving as active-duty firefighters everywhere.

Without you, this project would not have been possible.

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ACKNOWLEDGEMENTS

The successful completion of this project would not have been possible without the support and contributions of others, most noteworthy the City of Milwaukee Fire Department (MFD) and North Shore Fire Department (NSFD), and in particular, Health and Safety Officer Jason Mims and Battalion Chief Steven Brennan. I am indebted to these departments and individual for allowing access to various fire stations, equipment, facilities, and most importantly, the active-duty firefighters who participated in this study themselves. This type of collaboration is what allows for this type of a community-engage research project to become a reality – something that is no easy task.

I would also like to acknowledge and graciously thank my primary adviser, Dr. Kyle T. Ebersole. This project has ultimately been the culmination of six years of working together. I remember the very first meeting I was a part of with the MFD and hoped that one day a project like this would be able to take shape – and it has. I hope this leads to even more years of collaboration, and at times, frustration, between the two of us.

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Chapter I: Introduction

Background

The occupation of firefighting is considered to be one of the most dangerous occupations in the United States (Kurlick, 2009), as firefighters are 3.8 times more likely to suffer a work-related musculoskeletal injury (MSKI) than a private-sector worker (Seabury & McLaren, 2010). This high rate of MSKI has created an extremely large financial impact on fire departments across the United States (U.S.) with an estimated total annual cost attributed to injuries among firefighters between $2.8 to $7.8 billion per year (TriData Corporation, 2005). As such, interest in developing methods of identifying those at risk for developing a future MSKI and interventions designed to prevent these MSKIs from happening has grown among both the firefighter population, as well as among researchers and practitioners.

Previous research has demonstrated relationships between MSKI and dysfunctional neuromuscular control and neuromuscular imbalances (Page, Frank, & Lardner, 2010). In addition, theoretical links between altered functional movement patterns due to dysfunctional neuromuscular control (Clark & Lucett, 2011) and neuromuscular imbalances (Comerford & Mottram, 2001a; Comerford & Mottram, 2001b) have been proposed by researchers in the literature as well. As such, researchers have started to demonstrate the ability of functional movement assessments to predict future MSKI in various populations. These populations include traditional athlete populations (Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010; Garrison, Westrick, Johnson, & Benenson, 2015; Hotta et al., 2015; Kiesel, Butler, & Plisky, 2014; Kiesel, Plisky, & Voight, 2007; Mokha, Sprague, & Gatens, in press), as well as tactical athlete populations, such as the military (Knapik, Cosio-Lima, Reynolds, & Shumway, 2015; Lisman, O'Connor, Deuster, & Knapik, 2013; O'Connor, Deuster, Davis, Pappas, & Knapik,

2011) and firefighters (Butler, Contreras, Burton, Plisky, Goode, & Kiesel, 2013; Peate, Bates, Lunda, Francis, & Bellamy, 2007).

Due to the growing support of the use of functional movement assessments to predict future MSKI, the use of functional movement assessments has grown among practitioners as a method of quantifying overall functional movement quality (Cook & Burton, 2007; Cook, Burton, Hoogenboom, & Voight, 2014a; Cook, Burton, Hoogenboom, & Voight, 2014b) and identifying any possible underlying neuromuscular deficiencies that may be altering the observed functional movement patterns (Burton, Kiesel, & Cook, 2004; Cook, 2002; Cook, 2003; Cook, 2010; Hirth, 2007; Kiesel, Burton, & Cook, 2004; Kritz, Cronin, & Hume, 2009a; Kritz, Cronin, & Hume, 2009b; Ransdell & Murray, 2016). Two of these functional movement assessments include the Functional Movement Screen (FMS) and the Movement Efficiency (ME) Test, which is a component of the Fusionetics Human Performance System. These assessments both quantify the overall functional movement of an individual by creating a composite movement score (i.e., Total FMS score & Overall ME Test score, respectively).

In addition, various theoretical models of corrective exercise programming designed to restore optimal neuromuscular control and correct any identified neuromuscular imbalances have been proposed (Clark & Lucett, 2011). One such program is the Corrective Exercise Continuum created by the National Academy of Sports Medicine (NASM). This corrective exercise model is also utilized by the Fusionetics Human Performance System, with the goal of improving the functional movement quality of an individual by correcting the aforementioned neuromuscular deficiencies observed during the ME Test. Based on this theoretical framework, these corrective exercise programs would also subsequently lower the risk of MSKI of the individual as well.

However, there is currently a lack of research in the literature examining the influence of corrective exercise programming on functional movement quality. Furthermore, a corrective exercise intervention that utilizes the NASM Corrective Exercise Continuum has yet to be examined among the active-duty firefighter population. As such, it remains unknown if a corrective exercise intervention that utilizes this corrective exercise model is capable of significantly improving functional movement quality among active-duty firefighters.

Previous research has also demonstrated a link between measures of health and fitness and MSKI risk in the firefighter population (Jahnke, Poston, Haddock, & Jitnarin, 2013; Kuehl et al., 2012; Poplin, Roe, Peate, Harris, & Burgess, 2014; Poston, Jitnarin, Haddock, Jahnke, & Tuley, 2011). Due to these links between health and wellness and MSKI risk among firefighters, as well as the previously identified rates of MSKI among firefighters, the International Association of Fire Fighters (IAFF) and the International Association of Fire Chiefs (IAFC) have recently created The Fire Service Joint Labor Management Wellness-Fitness Initiative (WFI). This initiative is designed to improve the health and wellness, and subsequently decrease MSKI risk, among active-duty firefighters (International Association of Fire Fighters, 2008).

However, the WFI currently neglects the potential importance of functional movement assessments and the implementation of targeted corrective exercise programming. Since the literature has demonstrated a link between functional movement quality and MKSI risk among the firefighter population (Butler et al., 2013; Peate et al., 2007) and recent research suggests that health and fitness measures already incorporated into the WFI are associated with functional movement quality (Cornell, Gnacinski, Zamzow, Mims, & Ebersole, in press[a]; Cornell, Gnacinski, Zamzow, Mims, & Ebersole, in press[b], Cornell et al., unpublished laboratory data),

an examination of the influence of a corrective exercise intervention on measures of health and fitness among active-duty firefighters is warranted.

Finally, although the utilization of various functional movement screening tools has grown among practitioners, the FMS is currently the only method of quantifying functional movement quality being utilized in the research literature. However, since other assessments of functional movement quality are being utilized in the firefighter population, such as the ME Test, the examination of the criterion-reference validity of these other functional movement assessments to the already established FMS is warranted.

Specific Aims

Accordingly, the specific aims, and the respective purposes, hypotheses, scientific significance, and practical significance of each specific aim of this study were as follows:

Specific Aim #1. This study examined the influence of a four-week corrective exercise program intervention on measures of functional movement among active-duty firefighters through the use of a quasi-experimental design. Participants were placed into either the Corrective Exercise Program (CEP) group or the Control (CON) group in a counterbalanced fashion, based on their respective Overall ME Test score. Participants in the CEP group (n = 27) were given a four-week corrective exercise programming intervention and the four-week corrective exercise programming intervention for the participants in the CON group (n = 24) was deferred for four-weeks (i.e., a deferred treatment protocol). All corrective exercise programming was created through the Fusionetics Human Performance system, which utilizes the components of the NASM Corrective Exercise Continuum. Functional movement was quantified using the FMS and the ME Test associated with the Fusionetics Human Performance System (Total FMS score & Overall ME Test score, respectively).

Hypotheses. It was hypothesized that a four-week corrective exercise program intervention will significantly improve functional movement quality among active-duty firefighters. Specifically, it was hypothesized that a significant interaction effect between Group and Time would be identified. Furthermore, it was also hypothesized that significant simple effects of the Group (between) factor at Weeks 2 and 5 would be identified and that individuals in the CEP group would demonstrate significantly greater levels of functional movement (i.e., Total FMS & Overall ME Test scores) when compared to the CON group. This would imply that corrective exercise program interventions are capable of eliciting significant improvements in functional movement quality among active-duty firefighters. Thus, a short-term corrective exercise program may also significantly decrease the risk of future MSKI among the firefighter population.

Scientific significance. This study was the first of its kind to investigate the influence of a corrective exercise program intervention on functional movement quality within the active-duty firefighter population. Thus, this study has contributed to the literature by determining if a short-term (i.e., four-week) corrective exercise program intervention is capable of eliciting significant changes in functional movement quality within the firefighter population.

Practical significance. Since this study examined the influence of a corrective exercise intervention on functional movement quality among active-duty firefighters, this study also holds practical significance because it has determined if a short-term corrective exercise program can in fact reduce the MSKI risk within a cohort population that exhibits an extremely high rate of MSKI. Furthermore, since this study utilized the components of the NASM Corrective Exercise Continuum, this study has examined the potential evidence-based rationale for the use of this corrective exercise model among active-duty firefighters.

Specific Aim #2. This study also examined the influence of a four-week corrective exercise intervention on health and fitness measures that are already incorporated into the WFI and that have been previously associated with functional movement quality. These health and fitness measures included total body power output, lower extremity strength, and core muscular endurance.

Hypotheses. It was hypothesized that a corrective exercise program intervention would significantly improve these health and fitness measures of interest. This would imply that the targeted corrective exercise programming utilized by the Fusionetics Human Performance System is capable of improving measures of general health and fitness among active-duty firefighters as well.

Scientific significance. This study was the first of its kind to examine the influence of a corrective exercise intervention on health and fitness measures associated with the WFI. As such, this study has contributed to the literature by determining if a short-term corrective exercise intervention is capable of eliciting significant changes in these health and fitness measures of interest.

Practical significance. Since this study examined the influence of a corrective exercise intervention on various WFI health and fitness measures, this study also holds practical significance by determining if a short-term corrective exercise program can simultaneously improve these WFI health and fitness measures. Furthermore, the identification of methods to improve the health and fitness of active-duty firefighters is a growing area of interest of both researchers and practitioners, as well as within the firefighter community itself.

Specific Aim #3. Finally, this study examined the criterion-reference validity of the ME Test, a component of the Fusionetics Human Performance System, among active-duty

firefighters. To accomplish this, the Total FMS score was used as the criterion-reference in relation to Overall ME Test score.

***Hypothesis*.** It was hypothesized that a strong and positive (direct) relationship will be identified between Total FMS and Overall ME Test scores. This, in turn, would establish the criterion-reference validity the ME Test in the assessment of functional movement quality among the active-duty firefighter population.

***Scientific significance*.** This study has also contributed to the literature by being the first of its kind to examine the criterion-reference validity of the Overall ME Test scores associated with the Fusionetics Human Performance System to the already established Total FMS score.

***Practical significance*.** Finally, this study also holds practical significance as has determined if the ME Test holds criterion-reference validity when compared to the FMS. This is important for practitioners who utilize functional movement assessments as the ME Test is a tool that is growing in popularity within the firefighter population to quantify functional movement quality.

Delimitations

Participants were considered eligible for this study if they: (a) were fluent in speaking and writing English; (b) were at least 18 years of age; (c) were an active-duty firefighter; (d) were cleared by their fire department for full active-duty work; and (e) have been an active-duty firefighter for at least 12 months (i.e., one year). In addition, due to the fact that previous research has identified significant differences in functional movement quality between genders (Agresta, Slobodinsky, & Tucker, 2014; Anderson, Neumann, & Huxel Bliven, 2015; Knapik, Cosio-Lima, Reynolds, & Shumway, 2015; Letafatkar, Hadadnezhad, Shojaedin, & Mohamadi, 2014; Loudon, Parkerson-Mitchell, Hildebrand, & Teague, 2014), and that previous research

suggests that the Total FMS score is not measured equivalently between males and females (Gnacinski, Cornell, Meyer, Arvinen-Barrow, & Earl-Boehm, in press), only data from male active-duty firefighters were included in the statistical analyses utilized current study.

Participants were excluded from participating in this study if they: (a) suffered from chest pain or dizziness; (b) had been diagnosed with a heart condition; or (c) had been instructed by a physician or their Health and Safety Officer (HSO) to not participate in this study. In addition, in order to control for potential confounding factors of other corrective exercise training, participants were excluded from being placed into the intervention portion of this study if they were currently engaging in a structured corrective exercise program.

Assumptions

This study held the following assumptions: (a) that participants were accurate and truthful when completing the criteria for inclusion questionnaire; (b) that participants were in fact not concurrently engaged in other corrective exercise programming; (c) that participants provided maximal level of effort during the assessment of their functional movement quality and health and fitness levels; and (d) that participants were compliant with the corrective exercise intervention protocol, as well as accurately and truthfully completing their respective compliance questionnaires.

Limitations

Potential limitations of this study included: (a) experimenter error during the functional movement and health and fitness assessments; (b) the influence that the occupation of firefighting itself may have on measures of functional movement and health and fitness; and (c) the fact that the outcomes of this study are not generalizable outside of the active-duty firefighter population. In addition, the influence of other exercise training (i.e., aerobic exercise, resistance

exercise, etc.) the participant may have been currently engaging in may have also influenced the study measures. However, this was attempted to be controlled for by instructing the participants to maintain any other additional exercise programming in which they were already engaged in. Finally, the compliance level of each participant was a limitation as well. However, this was attempted to be controlled for through the use of compliance questionnaires that the participants completed each week.

Chapter II: Literature Review

Introduction

Firefighters are routinely asked to place themselves in dangerous situations and perform extremely intense physical activities, such as rescue victims, remove debris, and drag charged hoses (Gledhill & Jamnik, 1992; Hilyer, Weaver, Gibbs, Hunter, & Spruiell, 1999). In addition, previous research suggests that these occupational tasks are associated with average heart rates equivalent to 88% of an individual's heart rate maximum (Sothmann, Saupe, Jasenof, & Blaney, 1992; von Heimburg, Rasmussen, & Medbø, 2006). This combination of occupational hazards and intense physical demands places firefighters at risk for the development of numerous injuries and diseases (Smith, 2011). Accordingly, firefighting is considered to be one of the most dangerous occupations in the United States (Kurlick, 2009), as firefighters are 3.8 times more likely to suffer a work-related musculoskeletal injury (MSKI) than a private-sector worker (Seabury & McLaren, 2010). Specifically, the National Fire Protection Association (NFPA) estimates that 65,880 United States (U.S.) firefighters were injured in the line of duty in 2013 alone, with MSKIs (e.g., strains, sprains, or pain) accounting for 55.3% of all injuries (Karter Jr. & Molis, 2014). In addition, Poplin, Harris, Pollack, Peate, and Burgess (2012) estimate that 17.7 per 100 firefighters are injured each year in the U.S.

This high rate of MSKI has placed an extremely large financial impact on fire departments across the country. Leffer and Grizzell (2010) estimate that each injury results in an average medical cost of $13,420 upon a fire department. However, this estimate still does not take into account the back-fill pay and overtime hours required to compensate for the injured firefighter, as well as administrative costs and litigation fees associated with the resulting workers' compensation claims. When accounting for these additional expenses, the National

Institute of Standards and Technology estimates that the total annual costs attributed to injuries among firefighters is between $2.8 to $7.8 billion per year in the U.S. alone (TriData Corporation, 2005). Due to this extreme economic burden, many fire departments have implemented various initiatives to combat this dilemma. These initiatives include attempts to identify those at risk for future MSKIs and the implementation of exercise programming designed to prevent these MSKIs from happening.

As such, the following review of the literature will first briefly describe two of the commonly identified links to MSKI in the literature, dysfunctional neuromuscular control and neuromuscular imbalances, and the theoretical foundation supporting these mechanisms of MSKI. Based on this theoretical framework, the support for the use of functional movement screening to identify these neuromuscular deficiencies will be described and information regarding two commonly utilized functional movement assessments that are growing in popularity in the firefighter population will be provided. These functional movement assessments include the Functional Movement Screen and the Movement Efficiency Test. This review will then highlight previous research that suggests functional movement assessments can identify individuals at risk of future MSKI, including firefighters.

The following review will then describe how these functional movement assessments can be used to develop corrective exercise programs aimed at improving the altered movement patterns identified in the initial movement assessment. Specifically, this review will explain the Corrective Exercise Continuum developed by the National Academy of Sports Medicine (NASM) and why this model can be utilized as a theoretical framework when creating corrective exercise programming. In addition, the following will review the previous research that has examined the efficacy of utilizing the NASM Corrective Exercise Continuum, as well as other

previously utilized corrective exercise interventions in the literature, to improve functional movement quality.

The following review of the literature will then describe The Fire Service Joint Labor Management Wellness-Fitness Initiative, which was created by the International Association of Fire Fighters and the International Association of Fire Chiefs in 2008 (International Association of Fire Fighters, 2008). Since this wellness-fitness initiative is the nationally recognized health and fitness initiative being implemented among fire departments across the country, the potential influence corrective exercise programming on the health and fitness measures associated with this initiative is warranted. Accordingly, this review will then describe previously identified links in the literature between functional movement quality and the specific measures of health and fitness associated with the WFI among the firefighter population.

Based on the subsequent review, a gap in the literature regarding the efficacy of a corrective exercise program intervention on the enhancement of functional movement among active-duty firefighters will be identified. In addition, the lack of research examining the influence of a corrective exercise program on the health and fitness measures that have been previously linked to functional movement quality will be demonstrated. Furthermore, an argument will be made that the criterion-reference validity of the Fusionetics Human Performance System to the Functional Movement Screen should be examined.

Neuromuscular Deficiencies

Previous research has demonstrated relationships between MSKI and dysfunctional neuromuscular control (Leetun, Ireland, Willson, Ballantyne, & Davis, 2004; Hewett et al., 2005; Zazulak, Hewett, Reeves, Goldberg, & Cholewicki, 2007) and neuromuscular imbalances (Croiser, Ganteaume, Binet, Genty, & Ferret, 2008; Devan, Pescatello, Faghri, & Anderson,

2004; Knapik, Bauman, Jones, Harris, & Vaughan, 1991; Myer, Ford, Barber Foss, Liu, Nick, & Hewett, 2009; Nadler, Malanga, DePrince, Stitik, & Feinberg, 2000; Nadler et al., 2001; Niemuth, Johnson, Myers, & Thieman, 2005; Renkawitz, Boluki, & Grifka, 2006; Yeung, Suen, & Yeung, 2009).

Dysfunctional Neuromuscular Control. Dysfunctional neuromuscular control is theoretically a result of several physiological different mechanisms (Clark & Lucett, 2011). These mechanisms include: altered length-tension relationships; altered force-couple relationships; and altered arthrokinematics (Figure 1). Collectively, these mechanisms incorporate the muscular, nervous, and skeletal systems.

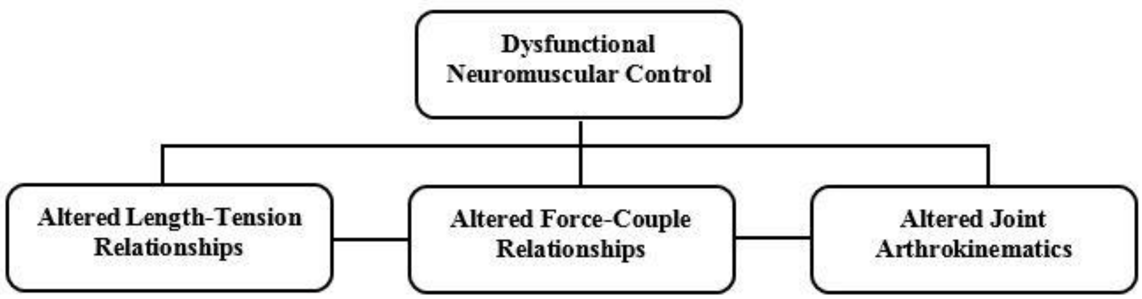

Figure 1. Mechanisms of dysfunctional neuromuscular control. Adapted from “An evidence-based approach to understanding human movement impairments” by M.A. Clark and S.C. Lucett, 2011, *NASM Essentials of Corrective Exercise Training* (1st ed., p. 63), Baltimore, MD: Lippincott Williams & Wilkins.

***Length-tension relationships*.** The length-tension relationship refers to the resting length of a respective muscle and the amount of tension (i.e., force) this muscle can produce at this given length (Neuman, 2010). This relationship is considered to be an “inverted U”, with an optimal zone of muscle length in reference to force creation. Due to improper posture or joint misalignment, a muscle can become adaptively shortened or lengthened (Kendall, McCreary, Provance, Rodgers, & Romani, 2005) in which case the force this muscle can create will be

inhibited or restricted, respectively. Accordingly, this altered length-tension relationship can directly result in dysfunctional neuromuscular control, as well as altered force-couple relationships and/or altered joint arthrokinematics (Figure 1).

***Altered force-couple relationships*.** In order to create force during a dynamic movement, groups of muscles surrounding a given joint will be synergistically recruited together (Kendall et al., 2005). This synergist recruitment of a group of muscles is called a force-couple (Clark & Lucett, 2011). If a group of muscles surrounding a joint are recruited in a non-synergistic fashion, an altered force-couple relationship within that joint occur. This altered force-couple relationship can occur due to previously altered length-tension relationships, as well as inappropriate muscle activation patterns. Accordingly, this altered force-couple relationship can directly result in dysfunctional neuromuscular control, as well as altered arthrokinematics and/or altered length-tension relationships (Figure 1).

***Altered joint arthrokinematics*.** Arthrokinematics refers to the motion that occurs between articular surfaces of a given joint (Neuman, 2010). These arthrokinematic motions are commonly referenced as roll, slide (or glide), and spin. Restricted arthrokinematic motion between two articular surfaces can result in an altered kinematic motion in the overall joint, which can result in an altered force-couple relationship of the muscles surrounding that joint, as well as vice versa (Clark & Lucett, 2011). Furthermore, restricted arthrokinematic motion in a joint can also directly result in dysfunctional neuromuscular control (Figure 1).

Neuromuscular Imbalances. Similar to altered neuromuscular control, muscle imbalances can also theoretically result in impaired functional movements as well (Comerford & Mottram, 2001a; Comerford & Mottram, 2001b). While muscle imbalances have many similarities to the altered mechanisms associated with dysfunctional neuromuscular control (e.g.,

altered length-tension relationships, etc.), muscle imbalances are traditionally defined in relation to the muscle length (short or long) and/or strength (strong or weak) between agonist and antagonist muscle groups and between contralateral (right vs. left) muscle groups (Page, Frank, & Lardner, 2010). For example, a commonly identified muscle imbalance is the *Lower-Crossed Syndrome*, which suggests that the abdominal and hip extensor muscle groups are weak and long and that the hip flexor and back extensor muscle groups are tight and short. However, muscle imbalances are also commonly observed between synergistic muscle pairs as well (Sahrmann, 2002). For example, although both muscles contribute to scapular retraction (adduction), it is common to observe a weak (long) lower trapezius and tight (short) rhomboids.

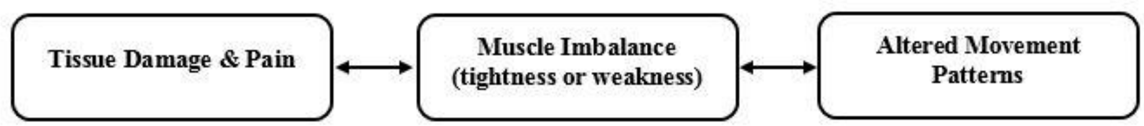

Figure 2. Muscle imbalance continuum. Adapted from "Structural and functional approaches to muscle imbalance" by P. Page, C.C. Frank, and R. Lardner, 2010, *Assessment and Treatment of Muscle Imbalance: The Janda Approach* (p. 6). Champaign, IL: Human Kinetics.

Dr. Vladimir Janda, who was among the first individuals to describe the theoretical rationale for the treatment of muscle imbalances, suggests that muscle imbalances should be considered as a continuum (Page et al., 2010). Based on this continuum, muscle imbalances are directly related to tissue damage and pain (i.e., MSKI), as well as altered functional movement patterns (Figure 2). In theory, altered functional movement patterns may cause muscle imbalances and vice versa. Similarly, previous MSKI or pain may have resulted in muscle imbalances and vice versa. Regardless, the muscle imbalance continuum suggests that the presence of neuromuscular imbalance(s) is central to development of altered functional

movement patterns and/or MSKI and pain (Comerford & Mottram, 2001a; Comerford & Mottram, 2001b).

Components of muscle imbalances. As previously stated, muscle imbalances are classically defined as tightness and/or weakness between directly related muscle groups. However, the components that create this tightness and/or weakness may consist of contractile and/or non-contractile components (Page et al., 2010).

Muscle tightness. According to Janda, the contractile components that may result in increased muscle tightness are increased limbic system activation, trigger point hypertonicity, and/or muscle spasms (Page et al., 2010). In addition, prolonged adaptive shortening will also exhibit as an increased muscle tightness from the loss of sarcomeres in series, resulting in a shorter resting muscle length (Kendall et al., 2005). Further adaptive shortening of the global musculature can result from shortening of the non-contractile components of muscle tissue as a result of changes in the viscoelastic properties of the muscle tissue as well (Page et al., 2010; Sahrmann, 2002; Sahrmann, 2011). This adaptive shortening could result from non-movement-related mechanisms, such as poor postural alignment, as well as movement-related mechanisms, such as repetitive motion on a factory assembly line (Sahrmann, 2002; Sahrmann, 2011). Furthermore, recent research suggests that these mechanisms of muscle tightness may also influence the muscle activation properties of antagonist musculature during functional movements, as restricted hip flexor muscle length has been linked to decreased gluteus maximus muscle activation during a squatting motion (Mills et al., 2015).

Muscle weakness. In contrast, Janda suggests that the contractile components that may result in increased muscle weakness include altered reciprocal inhibition, arthrogenic weakness (due to joint swelling, etc.), deafferentation of neuromuscular receptors (due to previous injury),

pseudo-weakness due to pain or trigger points, and fatigue (Page et al., 2010). In addition, based on the previously described length vs. tension relationship, muscles that have become adaptively lengthened or shortened, will also present as functionally weak (Kendall et al., 2005; Page et al., 2010; Sahrmann, 2002; Sahrmann, 2011).

Models of muscle imbalances. Although most corrective exercise interventions will typically always address underlying muscle imbalances an individual may be exhibiting, there are two different general philosophies on the etiology, presentation, and treatment of these muscle imbalances in regards to functional movement: the *biomechanical approach*, which is commonly associated with Shirley Sahrmann (Sahrmann, 2002; Sahrmann, 2011); and the *neuromuscular approach*, which is commonly associated with Vladimir Janda (Page et al., 2010). However, because both models include a combination of neural mechanisms, muscle tissue structure adaptations, and biomechanical principles, muscle imbalances will be collectively described as *neuromuscular imbalances* for the purposes of this document. In addition, the Corrective Exercise Continuum described later in this document will incorporate intervention elements of both models of neuromuscular imbalances.

Biomechanical approach. This neuromuscular imbalance approach postulates that sustained postures or repeated movements (e.g., occupational-related movements) cause muscle tissue changes over time. Specifically, muscles held in a lengthened positioned add sarcomeres in series and muscles held in a shortened position lose sarcomeres in series. This causes dissociated length-tension curves between synergistic muscles, with the more dominant muscle becoming short. These alterations in muscle tissues cause movement restrictions at various joints and these alterations should be identified at each individual joint. According to the *path of least resistance theory*, the result is compensatory motion at another joint, which is the

identifiable movement impairment during an actual functional movement (Sahrmann, 2001; Sahrmann, 2011). Over time, these maladaptations can lead to pain and MSKI, which is considered to be a movement impairment syndrome, due to laxity of joint ligaments, microtrauma to muscles and tendons, inflammation, etc. These changes are treated, and this movement impairment syndrome is theoretically corrected, by shortening (or activating) long muscles (via strengthening), reducing the tensile load on weak or long muscles, and supporting weakened or strained muscles.

Neuromuscular approach. Similar to the biomechanical approach, this neuromuscular imbalance approach also theorizes that sustained postures or repeated movements (e.g., occupational-related movements) can cause changes in muscle length over time (e.g., long and short). However, this approach theorizes that long muscles become neurologically inhibited (i.e., weak) and short muscles become neurologically overactive (e.g., spasms, trigger points, etc.). Over time, these neural changes alter the motion across involved joints, which in turn impairs the functional movement patterns displayed by the individual and can subsequently result in pain and MSKI (Page et al., 2010). Furthermore, this approach also postulates that proper proprioceptive information is required for proper motor regulation during functional movements and that the previously described altered joint motion causes a dysfunction in the transmission of this proprioceptive information back to the central nervous system. Therefore, this maladaptation further contributes to the altered movement patterns displayed by the individual. This approach also suggests that the evaluation of functional movement patterns is more important than the evaluation of individual muscle strength or individual joint motion. As such, although this approach suggests that proper neuromuscular balance should be restored, it is more concerned with proper neuromuscular coordination during functional movements, rather than

symmetrical muscle length and strength across individual joints. Therefore, the use of proprioceptive training to normalize neuromuscular balance and improve functional movement quality is emphasized in greater detail.

Summary. In summary, if either the global neuromuscular control of an individual becomes dysfunctional, or if the relationships between various muscle groups of an individual present in a neuromuscular imbalanced fashion, the literature suggests that the individual is at risk for greater MSKI, as well as impaired functional movement patterns.

Functional Movement Assessments

A functional movement has been previously described as a continuum of multi-joint body movement through the sagittal, frontal, and transverse planes (Boyle, 2010). Although any functional movement pattern requires motion, exhibiting adequate motion does not necessarily ensure normal functional movement quality, as other components (e.g., strength, stability, balance) are also required to complete the movement (Cook, 2010). As such, a functional movement assessment attempts to quantify the quality of an individual's functional movement by having the individual complete various multi-joint and single-joint gross movement patterns that collectively incorporate the three plans of motion.

Although the majority of the previous literature that has demonstrated relationships between neuromuscular deficiencies and MSKI has been isolated to single-joint assessments (e.g., ankle dorsiflexion range of motion, hip abductor muscle strength, etc.), these neuromuscular deficiencies may theoretically present themselves as impaired functional movement patterns as well (Clark & Lucett, 2011; Cook, 2010; Hirth, 2007; Liebenson, 2014; Mottram & Comerford, 2008; Page et al., 2010; Sahrmann, 2002; Sahrmann, 2011). Due to the growing support for this theoretical framework, various assessments have been created that

utilize functional movements in an attempt to identify the aforementioned dysfunctional neuromuscular control and neuromuscular imbalances (Teyhen et al., 2014a). Two of these assessments are the Functional Movement Screen and the Movement Efficiency Test.

Functional Movement Screen. The Functional Movement Screen (FMS) is an observational screening tool and protocol developed by Gray Cook and Lee Burton in the late 1990's to assess the fundamental movement patterns of an individual (Cook, 2003; Cook, 2010; Cook & Burton, 2007; Cook, Burton, Hoogenboom, & Voight, 2014a; Cook, Burton, Hoogenboom, & Voight, 2014b).

FMS sub-tests. The FMS utilizes seven different sub-tests that incorporate various *functional* movements (Cook, 2010). These sub-tests include: (a) a bilateral deep squat (DS); (b) a hurdle-step (HS); (c) an in-line lunge (IL); (d) a shoulder mobility (SM) test; (e) an active straight leg raise (ASLR); (f) a trunk stability (TS) push-up; and (g) a rotary stability (RS) test (Appendix A).

DS. The DS test begins with the individual standing straight, with their feet shoulder-width apart, toes pointed forward, and a dowel held overhead with their arms extended. The individual then squats to their lowest possible depth while attempting to maintain their arms overhead and a straight spine relative to their tibia. This is repeated several times and the rater views this movement from anterior, lateral, and posterior viewpoints.

HS. The HS test begins by measuring the height of the individual's tibial tuberosity. The rubber strap that runs across the FMS kit is then set to this height. The participant then places the dowel across their shoulders, parallel to the ground, and attempts to step over the rubber band hurdle and gently place their heel on the ground on the opposite side of the hurdle. The individual is then instructed to return to their original starting position. During these movements

the individual attempts to maintain balance, as well as a neutral spine, pelvis, and lower extremity (i.e. no rotation or abduction/adduction). This is repeated several times and the rater views this movement from anterior, lateral, and posterior viewpoints. This test is then repeated for the opposite limb as well.

IL. The IL test begins by having the individual assume a staggered stance position, with one foot in front of the other, equal to the length of their previously measured tibial tuberosity. The individual also holds the dowel against their back, with one arm over their head and one arm behind their back, in a reciprocal pattern of their legs. The individual then lunges forward, attempting to make contact with the heel of their lead foot, and then returns to their original starting position. During these movements the individual attempts to maintain a neutral spine and balance. This is repeated several times and the rater views this movement from anterior, lateral, and posterior viewpoints. This test is then repeated for the opposite limb as well.

SM. Before beginning the SM test, a SM clearance exam is performed bilaterally (Appendix A). If no pain is elicited during this clearance exam, the individual may perform the SH test. During the SH test, the individual makes fists with their hands, and in unison, reaches each fist towards the center of their back attempting to place them as close as possible. One arm will move over the top (shoulder flexion) and one arm will move underneath (should extension). The distance between the individual's fists is then measured. This movement is then repeated for the opposite limb.

ASLR. The ASLR beings by having the individual lying supine in the anatomical position (i.e., on back with palms facing up), with their knees fully extended and ankles pointed upwards (i.e., dorsiflexed). The dowel is positioned next to the leg that is being assessed according to the appropriate scoring criteria (Appendix A). The individual is instructed to

slowly raise their fully extended leg upwards in an attempt to clear the dowel (i.e., undergo hip flexion). This movement is then repeated for the opposite limb.

TS push-up. Before beginning the TS push-up test, a spinal extension clearance exam is performed (Appendix A). If no pain is elicited during this clearance exam, the individual may perform the TS push-up test. The TS push-up is performed in a similar fashion as a standard push-up, except the hand placement is modified based on the scoring criteria and gender of the individual (see Appendix A). The individual starts laying prone (i.e., face down) and then presses upwards into the top of the standard push-up position. During this movement the individual attempts to maintain a neutral spine and pelvis.

RS. Before beginning the RS test, a spinal flexion clearance exam is performed (Appendix A). If no pain is elicited during this clearance exam, the individual may perform the RS test. The RS test begins by positioning the FMS board underneath the person and in parallel with their spine (i.e., straddling the board). Based on the scoring criteria, the individual is instructed to raise their arm and knee off the group so that their elbow touches the appropriate knee. The individual is then instructed to return to the initial starting position. This movement is then repeated for the opposite limbs. During these movements the individual attempts to maintain a neutral spine and pelvis.

FMS scoring. Based on the movement deficiencies observed, each of the seven sub-tests of the FMS is scored 0 to 3, with 3 being the best (additional scoring descriptions for each FMS sub-test are provided in Appendix B). This results in a total possible score (i.e., Total FMS score) of 21 (Cook, 2010). If different FMS scores are demonstrated during the unilaterally assessed sub-tests (HS, IL, SM, ASLR, & RS tests), the lowest score is assigned to that respective sub-test. For example, if an individual scored a 3 for the right side and a 2 for the left

side during the IL, they would receive a final score of a 2 for the IL sub-test. As such, a greater Total FMS score is theoretically indicative of a greater quality of functional movement.

Movement Efficiency Test. The Movement Efficiency (ME) Test, which is associated with the Fusionetics Human Performance System, was developed by Michael Clark and formally introduced in 2013 by Fusionetics, LLC (Tai, 2015). Although the ME Test is a more recently introduced tool, the ME Test was originally developed from the various movement screens associated with the NASM Corrective Exercise Continuum (Clark & Lucett, 2011), which are further discussed below. However, the Fusionetics company expanded upon these movement screens by creating a 0–100 (worst–best) scoring system for each of these NASM movement screens, which became the various sub-tests of the ME Test, in an attempt to quantitatively describe the quality of the functional movement demonstrated during that sub-test. In addition, the Fusionetics Human Performance System also utilizes an algorithm to create specifically targeted corrective exercise programming that is designed to theoretically improve the individual's functional movement quality (and subsequent ME Test scores).

***ME Test sub-tests*.** The ME Test accomplishes this in a similar manner as the FMS and consists of seven different functional movement sub-tests as well (Appendix C). However, these functional movement sub-tests do differ slightly from the FMS. These sub-tests include: (a) a two-leg squat; (b) a two-leg squat with heel lift; (c) a one-leg squat; (d) a push-up; (e) shoulder movement tests; (f) trunk movement tests; and (g) cervical movement tests.

Two-leg squat. The two-leg squat test begins with the individual standing straight, with their feet shoulder-width apart, toes pointed forward, and their arms extended overhead. The individual then squats to roughly chair height while attempting to maintain their arms overhead and a straight and neutral spine. This test is repeated several times and the rater views this

movement from anterior, lateral, and posterior viewpoints. All observed movement compensations that correspond to the grading criteria are noted by the rater (Appendix D).

Two-leg squat with heel lift. The two-leg squat with heel lift test is performed in the same manner as the two-leg squat test, with the exception of placing two inch lifts underneath the individual's heels. This test is repeated several times and the rater views this movement from anterior, lateral, and posterior viewpoints. All observed movement compensations that correspond to the grading criteria are noted by the rater (Appendix D)

One-leg squat. The one-leg squat test begins by having the individual balance on one-leg, with their toes pointed forward, and their hands on their hips, with their non-involved leg left in a neutral position. The individual is then instructed to squat to roughly chair height while attempting to maintain balance and a neutral spine, pelvis, and knee alignment. This test is repeated several times and the rater views this movement from anterior, lateral, and posterior viewpoints. All observed movement compensations that correspond to the grading criteria are noted by the rater (Appendix D).

Push-up. The push-up test is essentially a standard push-up. In brief, the individual starts in the up-position of the push-up exercise, with their hands placed roughly shoulder-width and even with their chest. The individual then lowers themselves four to five inches from the ground and then presses upwards. This test is repeated several times and all observed movement compensations that correspond to the grading criteria are noted by the rater (Appendix D).

Shoulder movement tests. The ME Test shoulder movement tests begin by having the individual stand with their back facing the wall, feet hip-width apart, and their heels, buttocks, shoulders, and head touching the wall. In this same starting position, four separate shoulder movements are performed: flexion, internal rotation, external rotation, and horizontal abduction.

These movements are repeated several times for each arm and all observed movement compensations that correspond to the grading criteria are noted by the rater (Appendix D).

Trunk movement tests. The ME Test trunk movement tests begin by having the individual stand with their back facing the wall, feet hip-width apart, and their heels, buttocks, shoulders, and head touching the wall. In this starting position the individual performs the trunk lateral flexion movement by side bending and sliding their hand down the outside of their leg towards their knee. This movement is repeated several times for each side and all observed movement compensations that correspond to the grading criteria are noted by the rater (Appendix D). The individual then steps away from the wall and places their hands on their shoulders. From this new starting position, the individual performs the trunk rotation movement by rotating their upper body one direction as far as possible. This movement is repeated several times in each direction and all observed movement compensations that correspond to the grading criteria are noted by the rater (Appendix D).

Cervical movement tests. The ME Test trunk movement tests begin by having the individual stand with their feet shoulder-width apart and their arms by their sides. In this starting position the individual performs the cervical spine lateral flexion movement by laterally tipping their head in an attempt to move their ear to the shoulder. This movement is repeated several times in each direction and all observed movement compensations that correspond to the grading criteria are noted by the rater (Appendix D). From this same starting position, the individual then performs the cervical spine rotation movement by rotating their head to look over their shoulder. This movement is repeated several times in each direction and all observed movement compensations that correspond to the grading criteria are noted by the rater (Appendix D).

ME Test scoring. However, unlike the FMS, the ME Test utilizes binary scoring (i.e., yes/no) of each aspect of these respective movement patterns (Appendix D). Accordingly, if specific movement deviations are observed during each of these tests (e.g., dynamic knee valgus during the two-leg squat), the appropriate 'yes' check-box is selected. The associated Fusionetics Human Performance System software then calculates a ME Test score for each of these sub-test, which is scored on a 0 – 100 scale (Low – High), based on the indicated movement deviations and corresponding binary scoring of each functional movement. The Fusionetics software then averages the scores of these sub-tests to create an Overall ME Test score. As such, a greater Overall ME Test score is theoretically indicative of a greater quality of functional movement as well.

Summary. Due to the previously established links between MSKI and dysfunctional neuromuscular control and neuromuscular imbalances in the literature, the ability to identify these neuromuscular deficiencies in an attempt to prevent future MSKI is warranted. In addition, due to the theoretical rationale between neuromuscular deficiencies and altered functional movement patterns, the utilization of various functional movement screening tools (i.e., the FMS & ME Test) to identify the aforementioned neuromuscular deficiencies has grown among practitioners (Cook & Burton, 2007; Cook et al., 2014a; Cook et al., 2014b). However, although the utilization of functional movement screening tools has grown among practitioners, the FMS is currently the only method of quantifying functional movement quality being utilized in the literature. As such, the criterion-reference validity of other functional movement assessments, such as the ME Test, to the already established FMS, is currently still lacking in the literature.

Functional Movement Quality and Injury Risk

Based on the previously described theoretical links between functional movement patterns and neuromuscular control and neuromuscular balance, it is has been hypothesized that adequate neuromuscular control and neuromuscular balance along the kinetic chain are required to properly perform the various functional movement patterns associated with the FMS and ME Test. Since these neurophysiological factors have also been previously associated with MSKI risk, it has been hypothesized that functional movement quality is associated with MSKI risk as well (Cook et al., 2014a; Cook et al., 2014b). Accordingly, researchers have begun investigating if functional movement quality is associated with the development of future MSKI among various traditional athlete populations (e.g., basketball, volleyball, etc.), as well as *tactical athlete* populations, such as military cadets and firefighters.

Traditional athlete populations. The prospective association between functional movement quality and future MSKI among athletes was first described by Kiesel, Plisky, and Voight (2007). These researchers examined the ability of the FMS to predict the development of MSKI among professional football players ($N = 46$). FMS scores were collected prior to the start of the football season and MSKIs were tracked over the course of the football season. A MSKI was defined as being placed on the injured reserve list and/or a playing time loss of three weeks due to injury. An independent *t* test indicated that football players who suffered a MSKI demonstrated significantly ($t(44) = 5.62$, $p < .05$) lower Total FMS scores than football players who did not suffer a MSKI (14.3 ± 2.3 vs. 17.4 ± 3.1, respectively).

In addition, a receiver operator characteristic (ROC) curve was utilized to determine the sensitivity and specificity of the Total FMS score when predicting the binary outcome of incidence of injury (yes/no). This ROC curve analysis resulted in a maximum sensitivity and specificity of .54 and specificity of .91. Based on this maximal level sensitivity and specificity, a

Total FMS score of 14 was identified as a "cut-off" and a 2 × 2 contingency table (Total FMS score × Incidence of MSKI) was created based upon this cut-off value (Total FMS score ≤ 14 or ≥ 15). This contingency table was then utilized to calculate a statistically significant odds ratio (OR) of 11.67 (95% CI = 2.47 – 54.52). This implies that the odds of developing a MSKI is 11.67 times higher among a football player who demonstrates a Total FMS score ≤ 14 than a football player who demonstrates a Total FMS score ≥ 15.

Other researchers have utilized this Total FMS cut-off score of 14 described by Kiesel et al. (2007) to predict future MSKI as well. Garrison, Westrick, Johnson, and Benenson (2015) collected FMS scores from 160 collegiate athletes (males & females) prior to the start of their respective sport seasons (rugby, soccer, swimming, & diving) and the number of MSKIs each athlete suffered were tracked over the course of the season. Garrison et al. (2015) defined a MSKI as any MSK pain or complaint that: (a) affected athletic participation; (b) required consultation from a certified athletic trainer (ATC), a licensed physical therapist (PT), or physician; and (c) modified training for at least 24 hours or required protective splinting or taping in order to maintain participation. An independent *t* test indicated that athletes who suffered a MSKI demonstrated significantly ($p < .05$) lower Total FMS scores than athletes who did not suffer a MSKI (13.6 vs. 15.5, respectively). Based on the Total FMS score cut-off of 14 and the collected MSKI data, the researchers created a 2 × 2 contingency table (Total FMS score × Incidence of MSKI). This contingency table was then utilized to calculate a statistically significant OR of 5.61 (95% CI = 2.73 – 11.51). This implies that the odds of developing a MSKI is 5.61 times higher among an athlete who demonstrates a Total FMS score ≤ 14 than an athlete who demonstrates a Total FMS score ≥ 15.

In addition, Chorba, Chorba, Bouillon, Overmyer, and Landis (2010) collected FMS scores from 31 female collegiate athletes prior to the start of their respective sport seasons (soccer, volleyball, & basketball) and the number of MSKIs each athlete suffered were tracked over the course of the season. Chorba et al. (2010) defined a MSKI as an injury requiring medical attention or if the athlete sought advice related to a potential injury from an ATC, an athletic training student, or physician. Based on the Total FMS score cut-off of 14 and the collected MSKI data, the researchers created a similar 2 × 2 contingency table (Total FMS score × Incidence of MSKI). Although the 4.583 OR associated with this contingency table was not statistically significant (95% CI = 0.994 – 21.127), a significant correlation was identified between total injuries sustained and Total FMS score (r = -.726, p = .046).

This Total FMS cut-off score of 14 was later expanded upon by Kiesel, Butler, and Plisky (2014) by including whether or not the athlete demonstrated an asymmetry in FMS scores during the five unilaterally measured sub-tests (HS, IL, SM, ASLR, & RS tests). The researchers collected FMS scores from 238 professional football players prior to the start of their respective football seasons and MSKIs were tracked over the course of the football season. Kiesel et al. (2014) defined a MSKI as a MSKI that resulted in any time loss from either practice or competition games (excluding contusions). A one-way analysis of variance (ANOVA) indicated that football players who suffered a MSKI demonstrated significantly (p = .02) lower Total FMS scores than football players who did not suffer a MSKI (16.1 ± 1.8 vs. 17.4 ± 1.8, respectively). Based on the Total FMS score cut-off of 14 and the collected MSKI data, the researchers created a 2 × 2 contingency table (Total FMS score × Incidence of MSKI). This contingency table was then utilized to calculate a statistically significant relative risk (RR) ratio of 1.87 (95% CI = 1.20 – 2.96). This implies that football players who demonstrated a Total FMS score ≤ 14 were 1.87

times more likely to develop a MSKI than football players who demonstrated a Total FMS score ≥ 15.

Furthermore, these researchers also created an additional 2 × 2 contingency table based on if the athlete demonstrated a movement asymmetry on any of the unilateral FMS sub-tests and the collected MSKI data (FMS asymmetry × Incidence of MSKI). This contingency table was then utilized to calculate a statistically significant RR ratio of 1.80 (95% CI = 1.11 – 2.74). This implies that football players who demonstrated a FMS asymmetry were 1.80 times more likely to develop a MSKI than football players who did not demonstrated a FMS asymmetry.

Mokha, Sprague, and Gatens (in press) have also recently expanded the utilization of asymmetries in FMS sub-tests to predict MSKIs as well. The researchers collected FMS scores from 84 collegiate athletes (males = 20, females = 64) prior to the start of their respective sport seasons (rowers, volleyball, & soccer) and the number of MSKIs each athlete suffered were tracked over the course of the academic year by each team's ATC. These authors defined a MSKI as physical damage to the body (both contact and non-contact) secondary to athletic activity and/or an event for which the athlete sought medical care during an organized practice, strength and conditioning session, or competition. In addition, the injury must have required modified training for at least 24 hours or required protective splinting or taping for continued sport participation.

Mokha et al. (in press) then created a 2 × 2 contingency table similar to other previous studies (Total FMS score × Incidence of MSKI). Based on this contingency table, these researchers calculated a sensitivity of .26 and a sensitivity of .59 in regards to a Total FMS score of ≤ 14 predicting a future MSKI. In addition, an OR of 0.51 (95% CI = 0.20 – 1.29) and a RR ratio of 0.68 (95% CI = 0.39 – 1.19) were also calculated and athletes who sustained an MSKI

did not have a significantly (p > .05) lower FMS score than athletes who did not sustain an MSKI (15.8 ± 1.8 vs. 16.0 ±1.7, respectively). Thus, these researchers concluded that athletes who demonstrated a Total FMS score of ≤ 14 were no more likely to sustain an injury than those with a Total FMS score of ≥ 15 (χ^2 = 2.07, p = .15). Exploratory analyses using a ROC curve determined that a Total FMS score of ≤ 18 maximized the sensitivity (.83) and specificity (.80) in this athlete sample population. However, the subsequent OR of 0.56 (95% CI = 0.34 – 0.93) and RR ratio of 0.20 (95% CI = 0.02 – 1.90) still did not identify a statically significant relationship between demonstrating a Total FMS score of ≤ 18 and future MSKI.

In addition, Mokha et al. (in press) also created another 2 × 2 contingency table: FMS asymmetry or score of 1 on any sub-test × Incidence of MSKI. Based on this contingency table, these researchers calculated a sensitivity of .82 and a sensitivity of .54 in regards to a FMS asymmetry or score of 1 on any sub-test predicting a future MSKI. These researchers also calculated a statistically significant OR of 5.27 (95% CI = 1.93 – 14.40) and a RR ratio of 2.73 (95% CI = 1.36 – 5.44), and thus, these researchers concluded that athletes who demonstrated either a FMS asymmetry or score of 1 on any sub-test were 2.73 times more likely to sustain an injury than those with a Total FMS score of ≥ 15 (χ^2 = 11.39, p = .001). As such, although a Total FMS score of ≤ 14 may not have been a strong predictor of future MSKI in this athlete population, there does appear to be a significant relationship between asymmetries on the FMS and future MSKI risk.

Tactical athlete populations. The association between functional movement quality and future MSKI among tactical athlete populations has recently become a growing trend as well. According to Stephenson (2007), *tactical athletes* are defined as individuals serving in the military, or those who work as police, firefighters, and rescue personnel, who require speed,

strength, agility, endurance, and quickness to perform their job duties. Since the physiological requirements of these occupations are closely related to that of traditional athletes, the philosophy of implementing training interventions utilized among traditional athletes has grown in popularity. Concomitantly, the use of screening tools to assess functional movement quality, and subsequently MSKI risk, among these populations has grown as well.

***Military*.** The prospective association between functional movement quality and injury among the military tactical athlete population was first described O'Connor, Deuster, Davis, Pappas, and Knapik (2011). These researchers utilized a population of 874 Marine officer candidates that were enrolled into either short-cycle (n = 447) or long-cycle (n = 427) Marine officer training programs as participants. Researchers collected FMS and physical fitness data from these candidates before the start of their respective Marine officer training programs and incidents of any overuse, traumatic, and/or serious injury were monitored. Physical fitness was assessed through pull-ups, abdominal crunches, and three-mile run time test. A composite physical fitness score was quantified through the use of physical fitness test scoring criteria that is commonly utilized in the military (Headquarters Marine Corps, 2002).

By utilizing a ROC curve, O'Connor et al. (2011) determined that a Total FMS score of $\leq$14 maximized the ability of the FMS to predict the binary outcome of incidence of injury (yes/no) with a sensitivity and specificity .452 and .782, respectively. Specifically, the short-cycle candidates that demonstrated a Total FMS score $\leq$ 14 had a 1.91 times higher odds of injury than short-cycle candidates that demonstrated a Total FMS score $\geq$ 15 (95% CI = 1.21 – 3.01, p < .01) and the long-cycle candidates that demonstrated a Total FMS score $\leq$ 14 had a 1.65 times higher odds of injury than long-cycle candidates that demonstrated a Total FMS score $\geq$ 15 (95% CI = 1.05 – 2.59, p = .03). In addition, when all candidates were grouped together, the RR

ratio was 1.5 times greater with a Total FMS score of ≤ 14. Furthermore, the composite physical fitness score was also capable of predicting future injury as well. Specifically, candidates with a composite physical fitness score of < 280 had a 2.1 times higher odds of sustaining an injury than candidates with a composite physical fitness score of ≥ 280 (95% CI = 1.5 – 2.9, $p < .001$).

These relationships between functional movement, physical fitness, and MSKI among this population cohort were later elaborated by Lisman, O'Connor, Deuster, and Knapik (2013). When examining the physical fitness variables individually, the three-mile run time (RT) variable was able to significantly predict injury among the Marine officer candidates. Specifically, candidates with a three-mile RT of ≥ 20.5 minutes (i.e., a slower RT) had a 1.72 times higher odds of sustaining an injury than candidates with a three-mile RT of < 20.5 minutes (95% CI = 1.72 – 2.31, $p < .001$). Furthermore, through logistic regression modeling Lisman et al. (2013) also determined that the combination of a low Total FMS score and slow three-mile RT resulted in an even greater injury prediction ability. Specifically, candidates with a Total FMS score of ≤ 14 and a three-mile RT of ≥ 20.5 minutes had 4.19 times higher odds of sustaining an injury than candidates with a Total FMS score of ≥ 15 and a three-mile RT of < 20.5 minutes (95% CI = 2.33 – 7.53, $p < .001$). When coupled with the results of O'Connor et al. (2011), these findings suggest that not only is functional movement associated with future injury, but that physical fitness may also impact injury risk as well. However, even though Lisman et al. (2013) demonstrated that Total FMS score and three-mile RT were both capable of predicting future injury, these two variables were not significantly related to each other ($r = -.03$, $p > .05$). As such, the inter-variable relationships between functional movement and physical fitness, and how these characteristics relate to MSKI, remains largely unknown among the military population.

Recently, the largest prospective study examining functional movement quality and injury was conducted by Knapik, Cosio-Lima, Reynolds, and Shumway (2015). These researchers collected FMS data from 1045 Coast Guard cadets (770 males; 275 females) and prospectively collected data regarding the injuries that occurred during the cadet's respective eight-week Summer Warfare Annual Basic (SWAB) training program. The researchers defined an injury as any physical damage to the body that resulted in a clinic visit and was suspected to have been caused by the SWAB training. By utilizing a ROC curve, the researchers determined that the optimal Total FMS score cut-off that maximized the ability of the FMS to predict the binary outcome of incidence of injury (yes/no) differed based on gender. Specifically, the optimal Total FMS score cut-off for males was ≤ 11 (22% sensitivity & specificity 87%) and the optimal Total FMS score cut-off for females was ≤ 14 (60% sensitivity & specificity 61%).

Based on these identified cut-off points, Knapik et al. (2015) then utilized Chi-square tests and calculated RR ratios to determine injury risk among the male and female cadets. Among the male Coast Guard cadets, these researchers identified a statistically significant ($p < .01$) relative risk (RR) ratio of 1.64 (95% CI = 1.17 – 2.32). This implies that male cadets who demonstrated a Total FMS score ≤ 11 were 1.64 times more likely to develop an injury than male cadets who demonstrated a Total FMS score ≥ 12. Among the female Coast Guard cadets, these researchers identified a statistically significant ($p < .01$) relative risk (RR) ratio of 1.93 (95% CI = 1.27 – 2.95). This implies that female cadets who demonstrated a Total FMS score ≤ 14 were 1.93 times more likely to develop an injury than female cadets who demonstrated a Total FMS score ≥ 15. These results suggest that functional movement quality is capable of predicting future injury among the tactical athlete population of Coast Guard cadets. However, the

predictive mechanisms of functional movement tools (i.e., the FMS) may depend on the gender of the individual.

Firefighters. The association between functional movement quality and MSKI among the tactical athlete population of firefighters was first described by Peate, Bates, Lunda, Francis, and Bellamy (2007). These researchers collected FMS data from 433 firefighters and also collected retrospective MSKI history data and prospective MSKI incidence data for one year. Based on multiple regression analyses, the number of previous MSKIs significantly predicted ($p < .001$) Total FMS scores, after holding age constant. Specifically, each previous MSKI lowered Total FMS scores by 3.44 ($\beta = 3.44$) and this prediction model accounted for 66% of the total variance in Total FMS scores (Adj $R^2 = .661$). Although Peate et al. (2007) did not identify a significant prospective relationship between Total FMS scores incidence of MSKI (OR = 1.22, $p = .093$), this was attributed to the fact that the firefighters in this sample population underwent an injury prevention program focused around improving neuromuscular strength and stability of the core musculature. In fact, when the researchers compared the number of MSKIs during the year prior to the implementation of the injury prevention program, to the number of MSKI during the year following the implementation of the injury prevention program (39 vs. 22, respectively), there was a significant decrease ($p = .024$). As such, the authors concluded that there is a relationship between functional movement quality and previous MSKI among firefighters, and that the implementation of a core neuromuscular strength and stability program may mitigate this MSKI risk.

The association between functional movement quality and MSKI among the firefighter population was further explored by Butler, Contreras, Burton, Plisky, Goode, and Kiesel (2013). These researchers collected FMS data from 108 firefighter recruits before the start of a recruit

training program and collected injury data during this 16-week program. A MSKI was defined as any episode that caused the recruit to miss three consecutive days of training due to musculoskeletal pain, with the exception of burn injuries and wounds.

By utilizing a ROC curve, Butler et al. (2013) determined that a Total FMS score of ≤14 maximized the ability of the FMS to predict the binary outcome of incidence of injury (yes/no) with a sensitivity and specificity .83 and .62, respectively. Based on this cut-off criteria, the firefighter recruits that demonstrated a Total FMS score ≤ 14 had a 8.31 times higher odds of MSKI than firefighter recruits that demonstrated a Total FMS score ≥ 15 (95% CI = 3.2 – 21.6). Furthermore, logistic regression analyses identified statistically significant relationships between the development of a MSKI and two of the individual sub-tests of the FMS as well. Specifically, the DS and the TS push-up were significantly related to the development of a MSKI with ORs of 1.21 (95% CI = 1.01 – 1.42, β = 0.190) and 1.30 (95% CI = 1.07 – 1.53, β = 0.266), respectively. These results imply that functional movement quality is capable of predicting future MSKI among the firefighter recruit population as well. In addition, since core stability and strength are required to properly perform the TS push-up sub-test, Butler et al. (2013) also provides evidence in support for the proposed relationship between core strength and stability and MSKI risk that was previously hypothesized by Peate et al. (2007).

Summary. Based on the results of these previous studies, there appears to be growing evidence to support the use of functional movement assessments to predict future MSKI among both traditional athlete and tactical athlete populations. However, the vast majority of the literature has only utilized the FMS, which is only one of the functional movement assessments currently being utilized by practitioners. It is also important to note that there is not a universal definition of what constitutes a MSKI in the literature. In addition, the literature is currently

inconclusive on what should be the optimal cut-off Total FMS score, with researchers identifying appropriate cut-off scores ranging from 11 to 16. Furthermore, several studies have also not identified any ability of the Total FMS score to successfully predict future MSKI (Gribble et al., 2016; Warren, Smith, & Chimera, 2015; Wiese, Boone, Mattacola, McKeon, & Uhl, 2014), or have demonstrated low sensitivity (Hammes, aud der Fünten, Bizzini, & Meyer, in press) and/or positive predictive values (Bushman et al., 2016). Thus, it is possible that the relationship between functional movement and MSKI risk may be population specific (Knapik et al., 2015), or that the use of functional movement assessments may simply provide a general continuum of MSKI risk based on their overall functional movement quality. Furthermore, recent evidence suggests that some sub-tests may be more influential and/or informative than the Total FMS score in the prediction of MKSI risk (Bardenett et al., 2015; Hotta et al., 2015; Tee, Klingbiel, Collins, & Lambert, in press; Warren et al., 2015). As such, recent reviews and clinical commentaries suggest that caution should be taken when attempting to utilize functional movement assessments to place individuals into explicit injury risk categories (Dorrel, Long, Shaffer, & Myer, 2015; Kraus, Schutz, Taylor, & Doyscher, 2014; Krumrei, Flanagan, Bruner, & Durall, 2014; Wright et al., in press).

Nevertheless, the use of functional movement assessments to identify dysfunctional neuromuscular control and neuromuscular imbalances that may place an individual at a greater risk of MSKI has grown in popularity among practitioners over recent years (Burton, Kiesel, & Cook, 2004; Cook, 2002; Cook, 2003; Cook, 2010; Cook & Burton, 2007; Cook et al. 2014a, 2014b; Hirth, 2007; Kiesel, Burton, & Cook, 2004; Kritz, Cronin, & Hume, 2009a; Kritz, Cronin, & Hume, 2009b; Liebenson, 2014; Ransdell & Murray, 2016; Sahrmann, 2002; Sahrmann, 2011). Due to this increase in popularity, new technologies and platforms have

recently been developed that attempt to utilize the quantitative and qualitative data gathered during a functional movement assessment to create corrective exercise programming that is designed to address the identified dysfunctional neuromuscular control and neuromuscular imbalances. One such tool is the Fusionetics Human Performance System.

Fusionetics Human Performance System

The Fusionetics Human Performance System creates corrective exercise programming that is designed to correct the dysfunctional neuromuscular control and neuromuscular imbalances identified during the individual's ME Test. Theoretically, if these neuromuscular deficiencies are corrected, the functional movement quality (i.e., Overall ME Test score) of the individual will improve, and thus, the risk of future MSKI will decrease. The corrective exercise programming prescribed by the Fusionetics Human Performance System is based on the Corrective Exercise Continuum previously created by the NASM (Clark & Lucett, 2011).

NASM Corrective Exercise Continuum. The corrective exercise principles created by NASM are prescribed in an attempt to restore optimal neuromuscular control and correct any neuromuscular imbalances that an individual may be presenting with. Specifically, these corrective exercises attempt to address the individual's underlying neuromuscular deficiencies based on the following goals: (a) increasing dynamic range of motion (ROM) by inhibiting overactive muscular and lengthening tight musculature; (b) increasing neuromuscular strength by activating underactive musculature; and (c) integrating this newly created ROM and neuromuscular strength by performing functional exercises that incorporate dynamic movements (Clark & Lucett, 2011).

These goals are accomplished through a structured sequence of corrective exercise prescription (Figure 3). This progression of corrective exercises includes: (1) inhibit overactive

muscles; (2) lengthen tight muscles; (3) strengthen weak muscles; and (4) perform dynamic integration exercises (Clark & Lucett, 2011). Collectively, these corrective exercises will theoretically restore optimal neuromuscular control of the individual by restoring proper length-tension relationships, proper force-couple relationships, and proper arthrokinematics, as well as restore optimal neuromuscular balance of the individual by decreasing the observed muscle tightness and eliminating the observed muscle weakness.

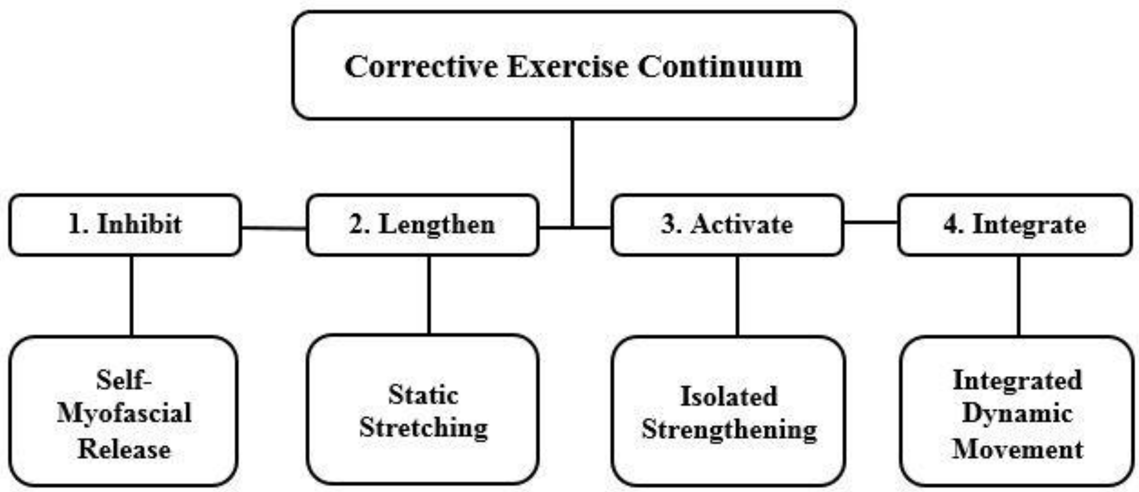

Figure 3. NASM Corrective Exercise Continuum. Adapted from "The rational for corrective exercises" by M.A. Clark and S.C. Lucett, 2011, *NASM Essentials of Corrective Exercise Training* (1st ed., p. 5), Baltimore, MD: Lippincott Williams & Wilkins.

***Inhibiting overactive musculature*.** The first step of the NASM Corrective Exercise Continuum consists of the inhibition of any overactive musculature that may be contributing to the altered functional movement patterns observed during the ME Test (Figure 3). For example, researchers have recently demonstrated that a restricted gastrocnemius/soleus muscle length (i.e., a neuromuscular imbalance), has been linked to excessive dynamic knee valgus during a two-legged squat (Bell et al., 2012; Bell, Padua, & Clark, 2008; Padua, Bell, & Clark, 2012) and the presence of a heel lift during a deep overhead squat (Noda & Verscheure, 2009). Thus, by

addressing this tight musculature, an individual may theoretically improve their functional movement quality.

Based on Janda's muscle imbalance continuum, muscle tightness may be due to the hyperactivity of muscle tissue as the result of increased limbic system activation, trigger point hypertonicity, and/or muscle spasms (Page et al., 2010). In order to inhibit the hyperactivity of this muscle tissue, practitioners have commonly utilized a technique known as myofascial release (Duncan, 2014). Traditional myofascial release techniques involve applying either direct pressure to the area of muscle tightness (Sefton, 2004a; Sefton, 2004b) and/or by applying compression with active or passive movements in an attempt to elongate the myofascial tissue surrounding the tight musculature (Sefton, 2004c). However, these traditional myofascial release techniques require the assistance of a practitioner to apply this pressure and movements. Recently, a new myofascial release technique, known as self-myofascial release (SMR), has grown in popularity. This SMR technique has become known as foam rolling because the individual can apply this compression to their overactive musculature through the use of a foam roller (Paolini, 2009; Schleip & Muller, 2013). As such, the NASM Correct Exercise Continuum supports the use of foam rolling as the preferred method of overactive musculature inhibition (Figure 3).

Previous research suggests that myofascial release techniques can decrease the level of hyperactivity of this muscle tissue by utilizing compression in an attempt to inhibit this musculature (Hanten, Olson, Butts, & Nowicki, 2000; Hou, Tsai, Cheng, Chung, & Hong, 2002). Theoretically, these myofascial release techniques this overactive musculature would be inhibited by the activation of Golgi tendon organs (GTOs), and other sensory receptors in the muscle tissue (e.g., Pacini corpuscles, Ruffini endings, etc.), due to the mechanical compression

placed on the muscle tissue (Schleip, 2003a). These sensory receptors would in turn decrease the resting hyperactivity of that muscle tissue by inhibiting the resting muscle activation through the alpha-gamma loop (Schleip, 2003b). As a result, this inhibition of overactive musculature would allow for a greater joint ROM due to a decreased hyperactivity of the musculature surrounding that given joint.

Although previous research does support an increase in joint ROM as a result of SMR (MacDonald et al., 2013; Sullivan, Silvey, Button, & Behm, 2013), there has been a lack of evidence suggesting that muscle activity is actually inhibited due to SMR (Mauntel, Clark, & Padua, 2014). Accordingly, it has been hypothesized that SMR primarily increases joint ROM by influencing the viscoelastic properties of the muscle tissue as a result of the mechanical compression forces and/or by altering autonomic function (Schleip, 2003a; Schleip, 2003b). Specifically, SMR may break-up adhesions that have formed in the myofascial matrix surrounding the muscle tissue (Barnes, 1997), as well as increase blood flow to muscle tissue through increased vasodilation (Okamoto, Masuhara, & Ikuta, 2014). Collectively, these mechanisms will hypothetically result in a change of the viscosity of muscle tissue, which will allow for a more pliable tissue (i.e., decrease muscle tightness), and thus, an improved joint ROM.

***Lengthening tight musculature*.** The second step of the NASM Corrective Exercise Continuum consists of the lengthening of any shortened musculature that may be contributing to the altered functional movement patterns observed during the ME Test (Figure 3). Based upon the previously described muscle imbalance continuum (Figure 2), muscle tightness may also be a result of the adaptive shortening of the non-contractile (or viscoelastic) components of muscle tissue (Page et al., 2010; Sahrmann, 2002; Sahrmann, 2011).

In order to lengthen shortened muscle tissue, practitioners have commonly utilized a technique known as static stretching (Johnson, 2012; Lardner, 2001). Static stretching involves passively or actively placing the joint in a position that elongates the targeted muscle tissue to a point of mild discomfort and holding this position for a period of time, usually ranging from 10-60 seconds (Nelson & Bandy, 2005). By placing and holding this tensile load on the muscle tissue, an improved joint ROM is theoretically created by increasing the extensibility of the musculotendinous unit (MTU) of the associated musculature (Alter, 2004; Lardner, 2001). Depending on the specific stretching employed, these viscoelastic changes in the MTU have been described as the adaptations of *creep* (constant pressure or torque) and *stress-relaxation* (constant position or angle), which result in a decrease in passive stiffness (tightness) of the associated musculature (Lis, de Castro, & Nordin, 2012; Taylor, Dalton, Seaber, & Garrett Jr, 1990). Although there is recent evidence for changes in MTU compliance as a result of static stretching among humans (Herda et al., 2011; Herda, Costa, Walter, Ryan, & Cramer, 2014; Reid & McNair, 2004; Ryan, Herda, Costa, Walter, & Cramer, 2012), there is still debate as to whether the length of the muscle tissue actually increases via viscoelastic deformation (Gajdosik, 2001). In contrast, it is possible that changes in the sensory receptors of the muscle tissue (e.g., GTOs, etc.) simply allow for a greater active extensibility of the tissue (Weppler & Magnusson, 2010). Nevertheless, static stretching has been routinely demonstrated as capable of improving the joint ROM of an individual (Decoster, Cleland, Altieri, & Russell, 2005; McHugh & Cosgrave, 2010; Nelson & Bandy, 2005). As such, the NASM Correct Exercise Continuum supports the use of static stretching as the preferred method of lengthening tight muscle tissue (Figure 3).

Strengthening weak musculature. The third step of the NASM Corrective Exercise Continuum consists of the strengthening of any weakened musculature that may be contributing to the altered functional movement patterns observed during the ME Test (Figure 3). Based on the previously identified mechanisms of dysfunctional neuromuscular control, a weakened muscle can result in altered length-tension relationships, altered force-couple relationships, and altered joint arthrokinematics (Figure 1). Due to these neuromuscular deficiencies, the agonist muscle (i.e., weak muscle) is not able to act as the prime mover and other synergistic musculature must become more dominate in order to complete the dynamic movement (Clark & Lucett, 2011). As such, this dysfunctional neuromuscular control theoretically further contributes to altered functional movement patterns observed during the ME Test. For example, hip abductor musculature weakness has been previously associated with poor single-leg squat performance (Crossley, Zhang, Schache, Bryant, & Cowan, 2011) and jump-landing kinematics (Jacobs, Uhl, Mattacola, Shapiro, & Rayens, 2007).

Resistance training has been routinely utilized by practitioners as a method of strengthening a given muscle or group of muscles (Haff & Triplett, 2016; Kraemer & Ratamess, 2004). This increase in muscular strength can be attributed to both neural and hypertrophic (i.e., an increase in muscle tissue) factors (Enoka, 2008; Kraemer, Ratamess, & French, 2002). However, previous research suggests that the initial increase in muscular strength, which is observed during the first few weeks of resistance training, is largely attributed to the neural factors associated with activating the muscle tissue (Kraemer, Fleck, & Evans, 1996). These neural factors include an increase in descending motor drive, an increase in motor neuron excitability, an increase in motor unit firing rates, and a decrease in neural inhibition of the muscle tissue (Aagaard, 2003).

Therefore, the initial strength training component of the NASM Corrective Exercise Continuum utilizes isolated strengthening of the weakened muscle(s) an attempt to facilitate increases in the neural factors associated with the activation of this musculature (Figure 3). Based on this theory, if increases in neural activation of the muscle can be achieved through resistance training, the force generating capacity of this specific muscle will be increased. Consequently, the functional movement patterns of the individual will theoretically improve due to enhanced neuromuscular control and less reliance on synergistic muscles to perform the movement and/or maintaining appropriate joint arthrokinematics (Clark & Lucett, 2011). For example, recent evidence suggests that strengthening of weak hip abductor musculature can lead to improved lower extremity running mechanics (Earl & Hoch, 2011; Snyder, Earl, O'Connor, & Ebersole, 2009) and single-leg squat motion (Willy & Davis, 2011).

***Integrating dynamic movements*.** The fourth step of the NASM Corrective Exercise Continuum consists of the dynamic integration of the newly created ROM from the first two steps of the continuum, with the newly created muscular strength from the third step of the continuum (Figure 3). Recent research suggests that increases in joint mobility alone (i.e., solely flexibility training) do not transfer over into improved functional movement patterns without the incorporation of dynamic training activities as well (Moreside & McGill, 2013). This lack of transferability is theoretically due to a lack of new motor control adaptations (i.e., intermuscular coordination) taking place in the previously limited range of motion (Cook, 2010).

Other previous research has also demonstrated the ability of various neuromuscular training programs to improve lower extremity biomechanics (Myer, Ford, Palumbo, & Hewett, 2005) and single-limb stability (Paterno, Myer, Ford, & Hewett, 2004) by incorporating dynamic strengthening exercises that emphasize stability and balance during functional movement (e.g.,

core strengthening, resistance training, plyometrics, balance perturbation, etc.). In addition, recent research has demonstrated greater increases in global neuromuscular activation of the stabilizing musculature when performing dynamic movements (e.g., single-leg, unstable, etc.) during resistance training when compared to the movements utilized during traditional resistance training modalities (e.g., bench press, double-leg squat, etc.) (Behm & Anderson, 2006; DiStefano, DiStefano, Frank, Clark, Padua, 2013; Marshall & Murphy, 2006). Furthermore, recent research also suggests that a dynamic skill acquisition training intervention was just as beneficial as a traditional strengthening program intervention at improving single-leg squat biomechanics (Dawson & Herrington, 2015). As such, various neuromuscular training methods are now becoming more commonly utilized among practitioners to improve the functional movement patterns of individuals in an attempt to decrease MSKI risk (Myer, Ford, Brent, & Hewett, 2012). Therefore, in order to improve the intermuscular coordination and neuromuscular activation of both agonist and synergist muscles, the NASM Corrective Exercise Continuum utilizes dynamic movement progressions during the final resistance training exercises in an attempt to improve dynamic neuromuscular control, and consequently, improve the functional movement patterns of the individual (Clark & Lucett, 2011).

Efficacy of the NASM Corrective Exercise Continuum. While each of the individual components associated with the NASM Corrective Exercise Continuum were developed based on evidence-based findings from recent literature, to date, there is very little evidence supporting the efficacy of this model in regards to the actual improvement of functional movement quality. Currently, only one study has utilized all components of the NASM Corrective Exercise Continuum during the corrective exercise intervention.

Bell, Oates, Clark, and Padua (2013) utilized the components of the NASM Corrective Exercise Continuum during a corrective exercise intervention among 32 participants who displayed medial knee displacement (two-dimensional observational analysis) and dynamic knee valgus (three-dimensional biomechanical assessment) during a two-leg overhead squat, which was the same two-leg squat assessment utilized by the Fusionetics ME Test and described by Hirth (2007). These researchers divided the participants into a corrective exercise group (n = 16), which receive the NASM corrective exercise intervention, and a control group (n = 16), which received no treatment and simply returned for follow-up testing three weeks later. The corrective exercise programming consisted of the inhibiting and lengthening the lateral gastrocnemius, soleus lateral hamstring, and adductors; isolated strengthening of the medial gastrocnemius, medial hamstring, and tibialis posterior; and dynamic balance exercises consisting of single-leg stance, single-leg reaches, single-leg squats, and single-leg hops. Participants in the corrective exercise group were prescribed corrective exercises that specifically targeted these goals three sessions per week, for three weeks, and were required to complete them at least two of the three sessions per week.

Bell et al. (2013) demonstrated that this corrective exercise intervention, based on the NASM Corrective Exercise Continuum, was capable of significantly reducing the amount of medial knee displacement ($F(1,150) = 4.43$, $p = .001$) and dynamic knee valgus ($F(1,150) = 3.40$, $p = .02$) during a two-leg overhead squat between control and corrective exercise groups during the post-intervention testing. In addition, active ankle dorsiflexion ROM (knee-extended) significantly increased ($t(1,30) = 2.8$, $p = .009$) in the corrective exercise group, suggesting that a previous neuromuscular imbalance in the ankle joint (i.e., tight plantarflexor musculature) had been corrected, which resulted in the improved functional movement pattern in the corrective

exercise group. As such, based on these results, the NASM Corrective Exercise Continuum is capable of eliciting significant improvements in functional movement quality. However, these improvements are currently only limited to the two-leg overhead squat motion. Therefore, it remains unknown if a corrective exercise intervention that utilizes the NASM Corrective Exercise Continuum is capable of significantly improving other aspects of functional movement (e.g., single-leg squat, shoulder movements, trunk movements, etc.) or if a NASM Corrective Exercise Continuum intervention protocol is capable of significantly improving overall ME Test score outcomes.

Efficacy of other corrective exercise interventions. While Bell et al. (2013) is currently the only study that examined the influence of a corrective exercise intervention that utilizes the NASM Corrective Exercise Continuum on functional movement quality, previous research has examined the influence of other exercise interventions on functional movement quality.

Evidence of support. Previous research has utilized other corrective exercise protocols in an attempt to improve functional movement quality as well. Kiesel, Plisky, & Butler (2011) examined the influence of a seven-week (4 days per week) corrective exercise intervention that utilized a corrective exercise protocol similar to the NASM Corrective Exercise Continuum on the functional movement quality among 62 professional American football players. These researchers incorporated both inhibiting and lengthening techniques (i.e., SMR and static stretching), as well as dynamic movement progressions in the corrective exercise intervention utilized in this study. However, these researchers did not include any isolated strengthening exercises and instead prescribed resistance training exercises focused solely on dynamic movement progressions (e.g., single-leg toe touches).

Kiesel et al. (2011) collected FMS score data both before and after the seven-week corrective exercise intervention. Based on the results the 2×2 RM ANOVA, there was a significant main effect of time ($F(1,61) = 180.4$, $p < .01$), with the Total FMS scores significantly increasing from pre- to post-intervention among both lineman and non-lineman (11.8 ± 1.8 vs. 13.3 ± 1.9; 14.8 ± 2.4 vs. 16.3 ± 2.4, respectively). In addition, based on Chi-square analyses, the number of professional American football players who demonstrated a Total FMS score > 14 significantly increased ($\chi^2 = 164.9$, $p < .01$) from pre- to post-intervention (7 vs. 30, respectively) and the number of professional American football players who did not demonstrate any bilateral asymmetry in any of the FMS sub-tests significantly increased ($\chi^2 = 7.8$, $p = .01$) from pre- to post-intervention as well (31 vs. 42, respectively). Thus, the authors concluded that the corrective exercise intervention was capable of reducing MSKI risk among professional American football players.

Bodden, Needham, and Chockalingam (2015) examined the influence of an eight-week corrective exercise intervention (4 sessions per week) among 25 mixed martial arts (MMA) athletes. Participants were placed into either an intervention or control group and researchers collected FMS score data both before and after the eight-week intervention. Results of the 2×2 RM ANOVA indicated a significant group by time interaction effect ($F(1,23) = 11.33$, $p < .001$). Follow-up analyses of the simple interaction effects indicated that the Total FMS score was significantly greater in the intervention group compared to the control group at Week 4 ($F(1,24) = 15.51$, $p = .001$) and Week 8 ($F(1,24) = 14.40$, $p = .001$). Furthermore, the Total FMS scores did not significantly increase from Week 4 to Week 8 in the intervention group ($p = 1.00$). In addition, Chi-square analyses indicated that significantly more participants demonstrated a Total FMS score > 14 in the intervention group compared to the control group at Weeks 4 ($\chi^2 = 7.29$, p

$< .01$) and Week 8 ($\chi^2 = 5.2$, $p \leq .05$). These results imply that the corrective exercise intervention yielded significant improvements in functional movement quality in only four weeks, but that no additional improvements were observed after four weeks. However, Bodden et al. (2015) did not provide information regarding the exercise selection utilized in the corrective exercise intervention. Although these researchers cite that a similar corrective exercise protocol to Kiesel et al. (2011) was utilized, it is difficult to ascertain the structure of this corrective exercise protocol or the principles that were followed.

Among *tactical athlete* populations, Cowen (2010) examined the influence of a six-week yoga class worksite-initiative among 77 active-duty firefighters. These yoga classes consisted of pranayama (breathing), asana (postures), and savasana (relaxation) techniques. Although information regarding the frequency of these yoga classes was not provided, the author did indicate that these classes were offered on-site and in the firehouses of the firefighters. While no control group was utilized this study, a paired *t* test indicated that the Total FMS score among these participants significantly increased ($t(76) = -12.49$, $p < .0005$) before and after the six-week yoga class worksite-initiative (13.3 ± 2.3 vs. 16.5 ± 2.2, respectively). As such, Cowen (2010) concluded that a worksite-initiative involving voluntarily attended yoga classes was capable of significantly improving functional movement outcomes among active-duty firefighters.

In addition, Goss, Christopher, Faulk, and Moore (2009) examined the influence of a six-week functional tactical training program among 90 Special Operations soldiers. This functional training program consisted of dynamic warm-ups, plyometric and agility training, stability and balance training, traditional power and strength training, and finally a structured cool-down utilizing SMR and static stretches. While no control group was utilized this study, a paired *t* test indicated that the Total FMS scores among these participants significantly increased ($p < .05$)

after the six-week functional tactical training program (15.14 vs. 17.62, respectively). As such, the authors concluded that it is possible that even traditional resistance training programming can result in improved functional movement outcomes if the modalities utilized in the training emphasize functional movement patterns (e.g., plyometrics, core training, squat progressions, etc.).

Evidence lacking support. Although there is evidence in the literature regarding the ability of corrective exercise programming to significantly increase functional movement quality through a corrective exercise intervention, several studies have also demonstrated a lack of evidence. For example, Beach, Frost, McGill, and Callaghan (2014) examined the influence of a 12-week exercise intervention on FMS scores among 60 firefighters. Participants were randomly divided into three groups (n = 20): (a) traditional fitness training (e.g., barbell weights, resistance training machines, etc.); (b) fitness training with functional movement emphasis (e.g., rotational movements, squatting movements, lunging movements, etc.); and (c) a control group. Researchers collected FMS scores both before and after the exercise training interventions. Wilcoxon signed-rank tests indicated that the FMS scores were not significantly different (p > .05) between groups both before and after the exercise training interventions. As such, although the exercise interventions significantly improved other measures of health and fitness (e.g., body fat percentage, flexibility, muscular strength, etc.), the functional movement quality of these participants did not significantly increase.

Wright, Portas, Evans, and Weston (2015) examined the influence of a four-week functional movement training intervention among 22 secondary school children. Participants were randomly divided into either the intervention or control groups (n = 11) and FMS scores, as well as other fitness measures, were collected both pre- and post-intervention. Participants in the

intervention group completed 30-minute functional movement training sessions four times per week that consisted of nine dynamic movements (e.g., crawling, pike walk, gluteal activation exercises, squatting, etc.). In contrast, participants in the control group participated in generic sporting activities that were similar to physical education class activities. These researchers concluded that only a trivial change in Total FMS scores occurred as a result of the functional movement intervention based on a Total FMS score increase difference of 0.2 ± 1.2 between groups, which was below the smallest worthwhile change criteria of 1.0 units. As such, the researchers suggested that an intervention consisting of generic sporting activities may influence functional movement quality to the same degree as a functional movement training intervention.

Summary. Although there is previous support in the literature regarding the ability of a corrective exercise intervention to significantly improve functional movement quality (and theoretically reduce MSKI risk), to date, there is currently one study that has utilized all components of the NASM Corrective Exercise Continuum in their corrective exercise intervention (Bell et al., 2013). In addition, this study only examined changes in knee frontal plane displacement (i.e., medial knee displacement & dynamic knee valgus) during the two-leg overhead squat test. As such, it remains unknown if this corrective exercise model is capable of significantly influencing other aspects of the ME Test.

Furthermore, although other researchers have examined the capability of other various corrective exercise interventions to significantly influence functional movement quality, the majority of these exercise interventions have only utilized exercises that predominantly require functional and/or dynamic movements and have excluded the targeted restoration of the observed neuromuscular imbalances through inhibition, lengthening, and isolated strengthening (i.e., steps 1-3 of the NASM Corrective Exercise Continuum). Finally, to date, only two studies have

utilized firefighters as their participants of interest (Beach et al., 2014; Cowen, 2010), with differing results in the effect of their respective exercise interventions on functional movement quality. As such, it remains unknown if a corrective exercise intervention that utilizes the NASM Corrective Exercise Continuum to develop the required exercise programming, such as the Fusionetics Human Performance System, is capable of improving functional movement quality, specifically among active-duty firefighters.

The Fire Service Joint Labor Management Wellness-Fitness Initiative

Due to the previously identified rates of MSKI among firefighters, the International Association of Fire Fighters (IAFF) and the International Association of Fire Chiefs (IAFC) have recently created The Fire Service Joint Labor Management Wellness-Fitness Initiative (WFI). One of the goals of this initiative is to improve the health and fitness of firefighters in an attempt to reduce the rate of MSKI in this population (International Association of Fire Fighters, 2008). The rationale for this WFI goal is based upon recent research that suggests that measures of health and fitness, such as obesity and aerobic fitness, are related to MSKI among active-duty firefighters.

For example, Jahnke, Poston, Haddock, and Jitnarin (2013) demonstrated that the odds of suffering a MSKI were 5.2 times higher (95% CI = 1.1 – 23.4) among obese firefighters, or firefighters with a body mass index (BMI) $\geq$ 30, than the odds of suffering a MSKI among normal weight firefighters (BMI = 18.5–24.9). Poston, Jitnarin, Haddock, Jahnke, and Tuley (2011) also demonstrated that firefighters who were classified as class II and III obese (BMI = 35–39.9; BMI $\geq$ 40, respectively) had almost five times the number of injury-related missed work days when compared to normal weight firefighters (OR = 4.89, 95% CI = 3.63 – 6.58) and Kuehl et al. (2012) demonstrated that the odds of filing a workers' compensation claim due to an

injury were 2.89 times higher (95% CI = 1.17 – 3.30, $p < .05$) among obese firefighters (BMI ≥ 30) than the odds of filing a workers' compensation claim due to an injury among normal weight firefighters (BMI = 18.5–24.9). In addition, Poplin, Roe, Peate, Harris, and Burgess (2014) demonstrated that a low degree of aerobic fitness, as determined by maximal aerobic capacity ($\dot{V}O_{2max}$), was also associated with future injury. Specifically, the odds of sustaining an injury was 2.2 times higher (95% CI = 1.72 – 2.88) among firefighters who were in the lowest aerobic fitness category ($\dot{V}O_{2max}$ < 43 mL/kg/min) when compared to firefighters who were in the highest aerobic fitness category ($\dot{V}O_{2max}$ > 48 mL/kg/min). Furthermore, Poplin, Roe, Burgess, Peate, and Harris (2016) also recently identified that firefighters who were placed into lowest overall fitness category were 2.90 (95% CI = 1.48 – 5.66) times as likely to have sustained any injury, as compared to individuals in the highest fire fitness category.

Therefore, the WFI includes recommendations and guidelines on how to implement health and fitness interventions into the active-duty firefighter population (International Association of Fire Fighters, 2008). These recommendations include sample exercise programming, exercise equipment cost analysis, and nutritional information. In addition, instructions regarding the administration of the health and fitness assessments endorsed by the IAFF and IAFC are provided. The health and fitness assessments chosen by the WFI are designed to assess obesity level, body composition, aerobic capacity, muscular power, muscular strength, muscular endurance, and flexibility of the firefighter. Furthermore, the IAFF and IAFC have also partnered with the American Council on Exercise (ACE) to create a Peer Fitness Trainer (PFT) certification. This certification is designed to train current active-duty firefighters to become competent with health and fitness assessments methods, as well as basic exercise

program design, with the intention of improving health and fitness programming and outcomes from within individual fire departments.

WFI measures and functional movement. However, although the WFI provides information regarding proper organizational structure to help facilitate injury rehabilitation within a fire department, the WFI currently does not include recommendations regarding functional movement assessment or corrective exercise programming. This is despite previous research suggesting that functional movement quality is related to MSKI risk in the firefighter population (Butler et al., 2013; Peate et al., 2007). In addition, the IAFF/IAFC/ACE PFT curriculum currently does not include functional movement assessment training or skill development.

Furthermore, the essential job demands associated with the firefighting occupation require numerous gross, whole-body, dynamic movement ability. For example, the *Standard on Comprehensive Occupational Medical Program for Fire Departments*, created by the NFPA, states that the essential job duties of a firefighter include: stair climb, ladder raise, hose drag, equipment carry, forced entry, victim search, rescue drag, and ceiling pull (NFPA, 2013). While these tasks all require minimal levels health and fitness (e.g., aerobic fitness, muscular strength, etc.), an argument can be made that these tasks also require a significant level of functional movement ability in order to safely and effectively execute these tasks. As such, although the WFI is attempting to decrease MSKI rates among the active-duty firefighter population by targeting health and fitness outcomes, an increased awareness of the role of functional movement assessments in the implementation of structure exercise programming among active-duty firefighters may be warranted.

Additionally, recent research suggests that health and fitness measures already incorporated into the WFI are associated with functional movement quality. For example, Cornell, Gnacinski, Zamzow, Mims, and Ebersole (in press[b]) identified a significant indirect relationship (r = -.235, p = .045) between Total FMS score and BMI among male firefighter recruits. This implies that as the functional movement quality (i.e., Total FMS score) of a firefighter recruit increases their obesity-level (i.e., BMI) decreases. In addition, Cornell, Gnacinski, Zamzow, Mims, and Ebersole (in press[a]) identified significant direct relationships between Total FMS score and barbell squat one-repetition maximal strength (1-RM_{Squat}), as well as between Total FMS score and prone plank time ($\%Plank_{max}$), among male firefighter recruits (r = .302, p = .007; r = .320, p = .004, respectively). This implies that as the functional movement quality (i.e., Total FMS score) of a firefighter recruit increases their lower extremity strength (1-RM_{Squat}) and core muscular endurance ($\%Plank_{max}$) increase. Upon further examination through the use of multiple regression analyses, the combination of BMI, 1-RM_{Squat}, and $\%Plank_{max}$ significantly predicted Total FMS scores of these male firefighter recruits ($F(3,74) = 5.043$, p = .003, R^2 = .170) as well. Finally, Cornell et al. (unpublished laboratory data) have also identified a significant direct relationship between Total FMS score and countermovement jump (CMJ) height among firefighter recruits (r = .392, p = .026). This implies that as the functional movement quality (i.e., Total FMS score) of a firefighter recruit increases their total body power output (CMJ) increases as well.

Taken together, these results suggest that the functional movement quality of firefighters is significantly related to many of the measures already associated with the WFI (i.e., obesity-level, muscular power output, muscular strength, & muscular endurance). In addition, based on these results, these health and fitness measures of interest may also improve with the

implementation of a corrective exercise program that is designed to improve functional movement quality. As such, future research should examine the influence of a corrective exercise intervention on functional movement quality, as well as measure of health and fitness, among the active-duty firefighter population.

Conclusion

Firefighters are 3.8 times more likely to suffer a work-related musculoskeletal injury (MSKI) than a private-sector worker (Seabury & McLaren, 2010) and it is estimated that 17.7 per 100 firefighters are injured each year in the U.S. alone (Poplin et al., 2012). The expenses associated with this high rate of MSKI creates an enormous financial impact on the municipality and a fire department. As such, further investigation into injury prevention interventions and programming among this population cohort are warranted.

Previous research has demonstrated relationships between MSKI and dysfunctional neuromuscular control (Leetun et al., 2004; Hewett et al., 2005; Zazulak et al., 2007) and neuromuscular imbalances (Croiser et al., 2008; Devan et al., 2004; Knapik et al., 1991; Myer et al., 2009; Nadler et al., 2000; Nadler et al., 2001; Niemuth et al., 2005; Renkawitz et al., 2006; Yeung et al., 2009). In addition, theoretical links between altered functional movement patterns due to dysfunctional neuromuscular control (Clark & Lucett, 2011) and neuromuscular imbalances (Comerford & Mottram, 2001a; Comerford & Mottram, 2001b; Page et al., 2010) have been proposed by researchers in the literature as well. In support of this theoretical link, researchers have started to demonstrate the ability of functional movement assessments to predict future MSKI in various populations (Chorba et al., 2010; Garrison et al., 2015; Hotta et al., 2015; Kiesel et al., 2007; Kiesel et al., 2014; Knapik et al., 2015; Lisman et al., 2013; Mokha et al., in press; O'Connor et al., 2011), including the tactical athlete population of firefighters (Butler et

al., 2013; Peate et al., 2007). As such, the use of functional movement assessments has grown among practitioners as a method of quantifying overall functional movement quality (Cook & Burton, 2007; Cook et al. 2014a, 2014b) and identifying and correcting these neuromuscular deficiencies (Burton et al., 2004; Cook, 2002; Cook, 2003; Cook, 2010; Hirth, 2007; Kiesel et al., 2004; Kritz et al., 2009a; Kritz et al., 2009b; Liebenson, 2014; Sahrmann, 2002; Sahrmann, 2011; Ransdell & Murray, 2016). Two of these functional movement assessments include the FMS and the ME Test, which quantify the overall functional movement of an individual by creating a composite movement score (i.e., Total FMS score & Overall ME Test score, respectively).

In addition, various theoretical models of corrective exercise programming designed to restore optimal neuromuscular control and correct any identified neuromuscular imbalances have been proposed, including the NASM Corrective Exercise Continuum (Figure 3). Based on this theoretical framework, these corrective exercise programs would also theoretically improve the functional movement quality of an individual as well (Clark & Lucett, 2011). Accordingly, properly prescribed corrective exercise programming would subsequently lower the risk of MSKI of the individual by correcting the previously identified neuromuscular deficiencies and by improving the functional movement quality of the individual.

Literature gap #1. However, there is currently a lack of research in the literature examining the influence of corrective exercise programming on functional movement quality. In addition, to date, there has only been one previous study examining the influence of a corrective exercise intervention that utilized all the components of the NASM Corrective Exercise Continuum (Bell et al., 2013). This study also only examined the influence of this corrective exercise intervention on changes in medial knee displacement during the two-leg overhead squat

motion. As such, it remains unknown if a corrective exercise intervention that utilizes the NASM Corrective Exercise Continuum is capable of significantly improving other aspects of functional movement (e.g., single-leg squat, shoulder movements, trunk movements, etc.) or if a NASM Corrective Exercise Continuum intervention protocol is capable of significantly improving overall functional movement (i.e., Total FMS score & Overall ME Test score outcomes). Furthermore, a corrective exercise intervention that utilizes the NASM Corrective Exercise Continuum has yet to be examined among the active-duty firefighter population.

Literature gap #2. Previous research has also demonstrated a link between measures of health and fitness and MSKI risk in the firefighter population (Jahnke et al., 2013; Kuehl et al., 2012; Poplin et al., 2014; Poston et al., 2011). Due to these links between health and wellness and MSKI risk among firefighters, the IAFF and IAFC have recently implemented the WFI, which is designed to improve the health and wellness and subsequently decrease MSKI risk among active-duty firefighters. However, this initiative currently neglects the importance of functional movement assessments and the implementation of targeted corrective exercise programming. Since the literature has demonstrated a link between functional movement quality and MKSI risk among the firefighter population (Butler et al., 2013; Peate et al., 2007) and recent research suggests that health and fitness measures already incorporated into the WFI are associated with functional movement quality (Cornell et al., in press[a], in press[b], Cornell et al., unpublished laboratory data), an examination of the influence of a corrective exercise intervention on measures of health and fitness among active-duty firefighters is warranted.

Literature gap #3. Finally, although the utilization of various functional movement screening tools has grown among practitioners, the FMS is currently the only method of quantifying functional movement quality being utilized in the research literature. Since other

assessments of functional movement are being utilized in the firefighter population, such as the ME Test, the criterion-reference validity of these other functional movement assessments to the already established FMS is warranted.

Chapter III: Methods

Introduction

Specific Aim #1. This study examined the influence of a four-week corrective exercise program intervention on measures of functional movement among active-duty firefighters. Functional movement was quantified using the Functional Movement Screen (FMS) and the Movement Efficiency (ME) Test associated with the Fusionetics Human Performance System (Total FMS score & Overall ME Test score, respectively). This study was the first of its kind to investigate the influence of a corrective exercise program intervention on functional movement within the active-duty firefighter population. Thus, this study has contributed to the literature by determining if a short-term (i.e., four-week) corrective exercise program intervention is capable of eliciting significant changes in functional movement quality in this population.

Specific Aim #2. This study also examined the influence of a four-week corrective exercise intervention on various health and fitness measures that have been previously associated with functional movement quality. These health and fitness measures include total body power output, lower extremity muscular strength, and core muscular endurance. These health and fitness measures are also associated with the already implemented The Fire Service Joint Labor Management Wellness-Fitness Initiative (WFI) created by the International Association of Fire Fighters (IAFF) and the International Association of Fire Chiefs (IAFC) (International Association of Fire Fighters, 2008). As such, this study has contributed to the literature by determining if a short-term corrective exercise intervention is capable of eliciting significant changes in these health and fitness measures of interest as well.

Specific Aim #3. Finally, although the use of the Fusionetics Human Performance System to create corrective exercise programs designed to improve functional movement quality

is growing in popularity, the Overall ME Test scores associated with this platform have never been compared to other established measures of functional movement. Accordingly, this study examined the criterion-reference validity of the Overall ME Test score among active-duty firefighters. In order to establish the criterion-reference validity of the Overall ME Test score, this measure was compared to another previously established measure of functional movement. Since the FMS has been previously utilized by researchers to quantify functional movement quality in the literature (Cook, Burton, Hoogenboom, & Voight, 2014a; Cook, Burton, Hoogenboom, & Voight, 2014b), as well as among practitioners to identify and correct functional movement deficiencies (Burton, Kiesel, & Cook, 2004; Cook, 2003; Cook, 2010; Kiesel, Burton, & Cook, 2004; Ransdell & Murray, 2016), the Total FMS score was used as the criterion-reference in relation to Overall ME Test score. As such, this study has also contributed to the literature by being the first study to examine the criterion-reference validity of the Overall ME Test scores associated with the Fusionetics Human Performance System to the already established Total FMS score.

Institutional Review Board

The protocol utilized in this study (IRB Protocol Number: 15.389) was approved (July 2, 2015) by the Institutional Review Board (IRB) of the University of Wisconsin-Milwaukee (UWM) before the beginning of any participant recruitment or the collection of any data (Appendix E). In addition, this study protocol was registered on ClinicalTrials.gov (ID Number: NCT02672735).

Recruitment. Upon IRB approval, recruitment began. All participants were recruited from the City of Milwaukee Fire Department (MFD) and the North Shore Fire Department (NSFD). Participants were recruited (with firefighter union and department approval) via word

of mouth, email correspondence, flyers being distributed at the individual firehouse and training academy (Appendix F), and information sessions given by researchers in the Human Performance and Sport Physiology Laboratory (HPSPL).

Informed consent. If a potential participant met the general eligibility criteria of this study, they were given written procedural information regarding all aspects of the study. All questions regarding the testing procedures, confidentiality, personal benefits, and/or any risks involved were answered. Participants were not coerced into participating by the research staff or their respective fire department and/or firefighter union. Upon admittance into the study, participants were given a unique participant code (e.g., CEP1) that was used to de-identify their personal information and ensure their data remained confidential. Each participant also created a personal log-in username and password that granted them access to the Fusionetics Human Performance System online platform. This ensured that, with the exception of the researchers, only the participant was able to access their Overall ME Test score data and respective corrective exercise programming.

Study Design

Phase 1. During Phase 1 of this study, anthropometric, functional movement, and health and fitness data were collected and all participants were invited to advance into Phase 2 of this study.

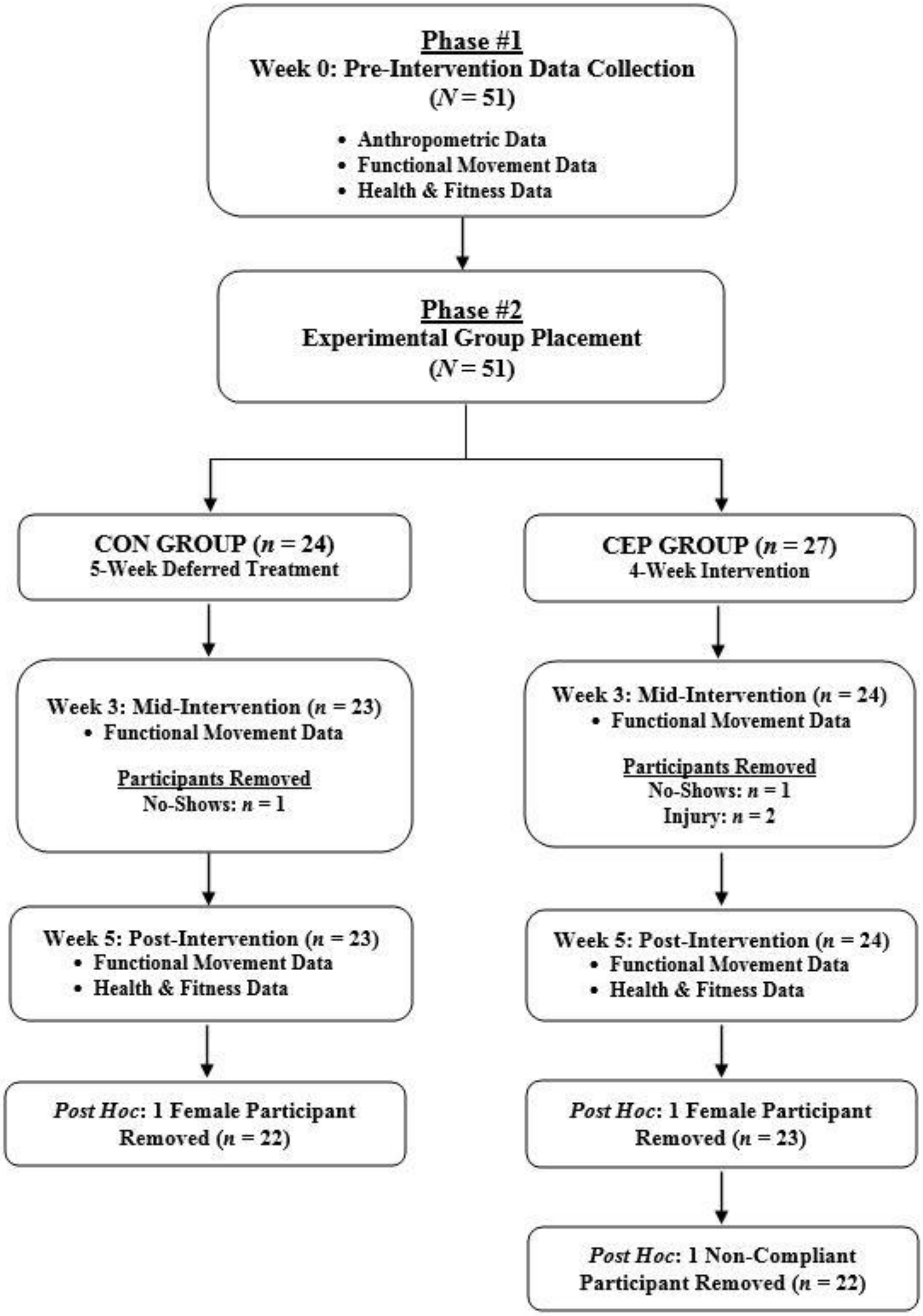

Figure 4. Overview of study design.

Phase 2. Phase 2 of the study was a quasi-experimental design intervention program. Specifically, Phase 2 involved the implementation of a four-week corrective exercise program intervention in which all data collected during the Phase 1 testing session represented each participant's pre-intervention (Week 0) time point of the corrective exercise program. All anthropometric, functional movement, and health and fitness data were collected again at the post-intervention (Week 5) time point. In addition, the measures of functional movement were collected at the mid-intervention (Week 3) time point. Participants that completed all aspects of Phase 2 received a participant honorarium consisting of $100 in gift cards.

***Experimental groups*.** Participants were placed into either the Corrective Exercise Program (CEP) group or the Control (CON) group (Figure 4). The primary researcher of this study was blinded to group membership, and thus, was not aware of which experimental group each participant was placed into during Phase 2 of the study.

In order to ensure similar baseline functional movement quality between the CEP and CON groups, participants were counterbalanced into CEP and CON groups based on their Week 0 Overall ME Test score. Specifically, the assignment of experimental groups alternated based on if participants scored between 0-49 and 50-100. Thus, the same number of participants scoring between 0-49 and 50-100 were counterbalanced (i.e., equal) between the CEP and CON groups. A follow-up independent samples t test confirmed that this counterbalancing resulted in no significant differences ($t(49) = 0.635$, $p = .528$) in Overall ME Test scores between the CEP and CON groups (44.1 ± 13.1 vs. 46.4 ± 12.2, respectively).

CEP group. Participants in the CEP group ($n = 27$) were given a four-week, four-days per week corrective exercise program intervention that was individually customized and

specifically designed to correct the neuromuscular imbalances and/or weakness responsible for the observed functional movement impairments.

CON group. Participants in the CON group (*n* = 24) were given a four-week corrective exercise program intervention in the same manner as the CEP group. However, the start of this corrective exercise programming was deferred for four-weeks (i.e., a deferred treatment protocol).

Participants

Accordingly, all 51 participants (49 males, 2 females) were active-duty firefighters from either the MFD (*n* = 42) or the NSFD (*n* = 9).

Criteria for Inclusion. Each participant first completed a Criteria for Inclusion Questionnaire (Appendix G). This questionnaire assessed the study eligibility and screened for any possible exclusionary criteria of each participant according to each Phase of this study.

***Study eligibility*.** Participants were considered eligible for this study if they: (a) were fluent in speaking and writing English; (b) were at least 18 years of age; (c) were an active-duty firefighter; (d) were cleared by their fire department for full active-duty work; and (e) had been an active-duty firefighter for at least 12 months (i.e., one year).

***Phase 1 exclusion criteria*.** Potential participants were excluded from Phase 1 of this study if they: (a) suffered from chest pain or dizziness; (b) had been diagnosed with a heart condition; or (c) had been instructed by a physician or their Health and Safety Officer (HSO) to not participate in this study.

***Phase 2 exclusion criteria*.** Participants were not allowed to engage in any other structured CEP, whether through the Fusionetics Human Performance System or otherwise. In addition, any participants who had a symptomatic orthopedic trauma that required medical

attention in the past three months, or any orthopedic surgery on their ankle, knee, hip, back (spine), or shoulder within the past year (12 months), were excluded from Phase 2 of this study.

Post hoc exclusion criteria. Due to the fact that previous research has identified significant differences in functional movement quality between genders (Agresta, Slobodinsky, & Tucker, 2014; Anderson, Neumann, & Huxel Bliven, 2015; Knapik, Cosio-Lima, Reynolds, & Shumway, 2015; Letafatkar, Hadadnezhad, Shojaedin, & Mohamadi, 2014; Loudon, Parkerson-Mitchell, Hildebrand, & Teague, 2014), and that previous research suggests that the Total FMS score is not measured equivalently between males and females (Gnacinski, Cornell, Meyer, Arvinen-Barrow, & Earl-Boehm, in press), all data associated with the 2 female firefighters included into the current study (MFD = 1, NSFD = 1) were excluded in all statistical analyses (Figure 4).

In addition, if a participant suffered a symptomatic ankle, knee, hip, back (spine), or shoulder trauma that required medical attention during the course of the study (n = 2), they were immediately removed as participants and not included in the statistical analyses involved in Specific Aims #1 and #2 of this study (Figure 4). Finally, if a participant did not self-report the completion of a minimum of three CEP training sessions per week, they were considered non-completers (n = 1) and were removed from the statistical analyses associated with Specific Aims #1 and #2 of this study (Figure 4).

Participant demographics. All participants also completed a demographics questionnaire (Appendix H). In total, these participants were stationed at 26 different firehouses across the MFD and NSFD. The mean ± standard deviation (*SD*) number of years of firefighting experience was 15.2 ± 7.5 years, with a range of 2 to 33 yrs. Twenty-three (45%) of these participants were firefighter / paramedics, eight (15.7%) were drivers / heavy equipment

operators, 14 (27.5%) were lieutenants, and six (11.8%) were captains. Forty-five (88.2%) of these participants were Caucasian/white, 2 (3.9%) were African American, 2 (3.9%) were mixed race, 1 (2%) was Native American, and 1 (2%) was Asian. Seven (13.8%) of these participants reported holding a bachelor's degree, 37 (72.5%) reported holding some post-high school education, five (9.8%) reported holding a high school diploma only, and two (3.9%) reported other levels of education. Forty-five of the 51 participants (88.2%) reported no previous experience completing any corrective exercise programming.

Table 1

Participant Descriptive Data

Age (yrs)	Mean	*SD*	Range
Total (*N* = 51)	41.0	7.8	27 – 59
MFD (*n* = 42)	41.4	8.1	27 – 59
NSFD (*n* = 9)	39.1	6.3	29 – 50
Height (cm)	**Mean**	***SD***	**Range**
Total (*N* = 51)	178.7	6.0	159.9 – 191.0
MFD (*n* = 42)	178.5	5.9	159.9 – 191.0
NSFD (*n* = 9)	179.6	6.7	170.2 – 189.0
Weight (kg)	**Mean**	***SD***	**Range**
Total (*N* = 51)	89.9	10.3	57.3 – 108.6
MFD (*n* = 42)	90.2	10.7	57.3 – 108.6
NSFD (*n* = 9)	88.8	8.1	77.2 – 96.4
BMI (kg/m^2)	**Mean**	***SD***	**Range**
Total (*N* = 51)	28.1	2.9	22.4 – 35.6
MFD (*n* = 42)	28.3	3.1	22.4 – 35.6
NSFD (*n* = 9)	27.5	1.5	25.9 – 29.6

Note: yrs, years; centimeter, cm; kilogram, kg; m^2, meters squared.

In addition, descriptive data of the physical variables among all participants can be found in Table 1. Independent samples *t* tests indicated no statistically significant differences in age, height, weight, or body mass index (BMI) between fire departments ($t(49) = 0.781$, $p = .438$; $t(49) = -0.494$, $p = .623$; $t(49) = 0.359$, $p = .721$; $t(49) = 0.738$, $p = .464$, respectively).

Settings

Testing Locations. All anthropometric, functional movement, and health and fitness data was collected at the Station #5 (1313 W. Reservoir Avenue, Milwaukee, WI 53205) for all MFD participants and Station #82 (5901 N. Milwaukee River Parkway Glendale, WI 53209) for all NSFD participants. Data was collected at this location in an attempt make the data collection process convenient for the participants and to ensure that the participants are in a comfortable environment.

Corrective exercise program intervention locations. Participants completed their corrective exercise programming sessions at either their own respective firehouse or Station #5 and/or Station #82 for MFD and NSFD participants, respectively. Having the option of completing their corrective exercise sessions in two different locations provided the participants with the proper resources to complete their sessions both on-duty and off-duty. This step was taken to ensure that each participant had two different options to complete their corrective exercise program sessions in order to help facilitate compliance and decrease attrition risk.

Firehouses. All 36 firehouses in the MFD and five firehouses in the NSFD were equipped with various corrective exercise equipment (Appendix I). In addition, both the MFD and NSFD recently purchased and placed various resistance training equipment in all firehouses as well (e.g., sandbags, medicine balls, etc.).

Data Collection Procedures

To ensure accuracy and reliability, all study measures were collected by the same researcher. All study measures were collected in the following order during the pre-intervention and post-intervention (Week 0 and Week 5, respectively) testing sessions. Only functional movement data was collected during the mid-intervention (Week 3) testing session. Participants were instructed to refrain from voluntarily participating in any exercise or training that may result in muscle soreness the 48 hours prior to data collection.

Anthropometric measures. All anthropometric measures were collected and calculated according to guidelines created by the American College of Sports Medicine (ACSM) (American College of Sports Medicine, 2014), unless otherwise indicated.

Age. The age of each participant was collected and recorded in yrs.

Height and weight. The height and weight of each participant was measured with a medical balance-beam scale and stadiometer (Detecto, Webb City, MO) to the nearest cm and kg, respectively.

Obesity. BMI is a commonly utilized measures of obesity-level (World Health Organization, 2000). As such, the obesity-level of each participant was assessed by utilizing the previously collected height and weight data to calculate the BMI of each participant by dividing their respective weight by height squared (kg/m^2).

Functional movement. After all anthropometric measures were collected, measures of functional movement data was collected. However, before any functional movement data was collected, participants first completed a dynamic warm-up that progressed in intensity and lasts approximately five-minutes. This dynamic warm-up has been previously utilized the population of firefighters (Cornell, Gnacinski, Langford, Mims, & Ebersole, 2015) and consists of: walking

lunges, walking toe touches, high knees, power skips, side shuffles, carioca, and a sprint. Functional movement was quantified as the Total FMS score and Overall ME Test score of each participant.

FMS data**.** FMS data was collected by utilizing a FMS test kit (Functional Movement Systems, Chatham, VA) and by methods previously described in the literature (Cook et al., 2014a, 2014b). The FMS consists of seven separate sub-tests, including: (a) a bilateral deep squat (DS); (b) a hurdle-step (HS); (c) an in-line lunge (IL); (d) a shoulder mobility (SM) test; (e) an active straight leg raise (ASLR); (f) a trunk stability (TS) push-up; and (g) a rotary stability (RS) test (Appendix A). Each of the seven sub-tests of the FMS were scored 0 to 3 (worst-to-best), for a total possible score (Total FMS score) of 21. Based on the movement deficiencies observed a score for each sub-test was given (Appendix B): (a) a score of 3 was given for performing the functional movement perfectly; (b) a score of 2 was given when the functional movement was completed, but with some compensatory movements observed; and (c) a score of 1 was given when the participant could not successfully complete the movement. If different FMS scores were demonstrated during the unilaterally assessed sub-tests (HS, IL, SM, ASLR, & RS tests), the lowest score was assigned to that respective sub-test. Finally, a score of 0 was given for a sub-test if the movement, or the associated shoulder and spine clearing exams, elicited any pain. Due to previous research suggesting that knowledge of the scoring criteria can influence FMS scoring (Frost, Beach, Callaghan, & McGill, 2015), no feedback regarding the scores of each sub-test or Total FMS score were provided to the participants during each testing session (Week 0, Week 3, or Week 5).

Although previous research has demonstrated a wide range of inter-rater reliability for Total FMS scores (*ICC*s = .37 – .98) and for individual FMS sub-tests (*ICC*s = .30 – .89) (Gulgin

& Hoogenboom, 2014; Minick et al., 2010; Onate et al., 2012; Shultz, Anderson, Matheson, Marcello, & Besier, 2013; Smith, Chimera, Wright, & Warren, 2013), a recent meta-analysis conducted by Cuchna, Hoch, and Hoch (in press) indicated moderate evidence for good inter-rater reliability (summary *ICC* = .843 [95% CI = .640 – .936]), as well as intra-rater reliability (summary *ICC* = .869 [95% CI = .785 – .921]). In addition, Gribble, Brigle, Pietrosimone, Pfile, and Webster (2013) suggested that the intra-rater reliability is markedly higher among experienced practitioners (*ICC* = .95). Accordingly, the literature in general suggests that there is a moderate level of evidence in favor of fair-to-excellent inter-rater and intra-rater reliability of the FMS when scored live (vs. video) with acceptable levels of measurement error (Beardsley & Contreras, 2014; Cuchna et al., in press; Moran, Schneiders, Major, & Sullivan, in press). Furthermore, the primary researcher of the current study has also previously exhibited good-to-excellent intra-rater reliability (*ICC* = .87) for Total FMS scores (Cornell et al., unpublished laboratory data).

ME Test data. ME Test score data was collected by utilizing the ME Test of the Fusionetics Human Performance System (Fusionetics, Alpharetta, GA). The ME Test assesses the gross movement ability of an individual in a similar manner as the FMS, which has been previously described by Cook et al. (2014a, 2014b). In brief, the ME Test also consists of seven different functional movement tests, including: a two-leg squat; a two-leg squat with heel lift; a one-leg squat; a push-up; shoulder movement tests; trunk movement tests; and cervical movement tests (Appendix C). However, unlike the FMS, the ME Test utilizes binomial scoring (i.e., yes/no) of each aspect of these respective movement patterns (Appendix D). Accordingly, if specific movement deviations were observed during each of these sub-tests (e.g., dynamic knee valgus during the two-leg squat), the appropriate 'yes' check-box was selected in the

Fusionetics Human Performance System software platform. This software then calculated a ME Test score, which is scored on a 0 – 100 scale (Low – High), based on the indicated movement deviations for each functional movement of the ME Test. These seven scores were then compiled by the system to create an Overall ME Test score (0 – 100) for the individual.

Previous research has demonstrated excellent inter-rater reliability (*ICC* = .970) for the Overall ME Test score and good-to-moderate reliability (*ICC*s = .750 – .976) for the individual ME sub-tests (Cornell & Ebersole, 2016). However, the intra-rater reliability of the Fusionetics ME Test has not yet been reported in the literature.

Health and fitness measures. The following health and fitness measures were collected in the following order and measured according to the guidelines created by the ACSM (American College of Sports Medicine, 2014), unless otherwise indicated. These measures of health and fitness were chosen because they are also utilized by the WFI (International Association of Fire Fighters, 2008).

Total body power output. Total body power output was examined by performing a countermovement jump (CMJ), which is a field-test commonly utilized by practitioners to examine total body power output (McGuigan, 2016). CMJ height (cm) will be assessed using a vertical jump mat (Probotics Inc., Huntsville, AL). This device calculates vertical jump height based upon the flight time of the individual and the previously identified correction factor will be applied to the vertical jump height (McMahon, Jones, & Comfort, in press). Previous research has demonstrated excellent criterion-reference validity (*r* = .967) of the ability of this vertical jump mat to assess vertical jump height compared to assessing vertical jump height via a three-camera system (Leard et al., 2007). In addition, Markovic, Dizdar, Jukic, & Cardinale (2004)

suggests that the CMJ test has the greatest factorial validity to explosive power output (r = .87) and exhibits excellent reliability (Cronbach's α = .98).

In brief, participants stood on the jump mat in an upright position with their feet parallel to each other and shoulder-width apart. Participants then performed a quick countermovement by flexing at the hips, knees, and ankles and extending their arms backwards. Once reaching their preferred depth of countermovement descent, participants explosively extended at the hips, knees, and ankles (i.e., triple extension) and simultaneously swing their arms upward in an attempt to jump as high as possible. Three trials were performed and the height of the trial resulting in the highest CMJ height was recorded in cm.

Lower extremity muscular strength. Lower extremity muscular strength was assessed bilaterally by performing a one-repetition maximal isometric deadlift ($1RM_{Deadlift}$) exercise. The force output generated during this isometric exercise was measured using the Jackson Strength System (Lafeyette Instrument Company, Lafayette, IN) and according to the protocol described by the WFI (International Association of Fire Fighters, 2008). In brief, each participant was instructed to stand on the platform in a deadlift position (neutral spine, knees slightly bent, arms extended, looking forward), with feet shoulder-width apart. The participant then performed an isometric deadlift by attempting to lift the V-grip handlebar, which was secured to the platform, upwards while maintaining this deadlift position. A warm-up trial (roughly 50% of their maximal effort) was completed first, followed by three testing trials, with 30 seconds of rest given between each trial. The trial resulting in the greatest $1RM_{Deadlift}$ force output was recorded in kg and normalized to each participant's respective body weight (kg/kg).

Core muscular endurance. The maximal prone plank time ($Plank_{max}$) is a commonly utilized test to assess the endurance capacity of the core musculature (Reiman & Manske, 2009).

In brief, each participant was instructed to lay prone, keeping their upper body elevated and supported by the elbows. Participants then supported their body on their forearms and toes, raising their hips and legs off the floor. Participants maintained this neutral position until fatigue or pain caused them to volitionally terminate the test. Total time to complete the test was then recorded in seconds (sec).

Previous research suggests that this prone plank test is considered a valid and reliable assessment of core muscular endurance with excellent test-retest reliability ($r = .78$, $p < .05$) among men and women (Schellenberg, Lang, Chan, & Burnham, 2007).

Corrective Exercise Program Interventions

All individually-tailored corrective exercise programs were created using the Fusionetics Human Performance System software (Fusionetics, Alpharetta, GA). Based on the functional movement patterns displayed by each participant, this software uses an algorithm to not only calculate their ME Test score, but to identify potential deficiencies in neuromuscular control, lack of core stability and strength, and neuromuscular imbalances. Accordingly, four weeks of corrective exercise programming was then recommended by the software to address these deficiencies, and in turn, correct the previously observed functional movement patterns impairments.

All CEPs were completed unsupervised by the primary researcher. The co-Principal Investigator and certified peer fitness trainers (PFTs) within each department were available to the participants to ask questions regarding their individual programming. However, the delivery of the actual programming was guided through the Fusionetics Human Performance System software and completed by each participant on their own.

Intervention protocol. A corrective exercise program intervention protocol similar to Bell, Oates, Clark, and Padua (2013) was utilized, in which participants were given a four-session per week corrective exercise program. In addition, based on the NASM Corrective Exercise continuum, improvements in functional movement quality should theoretically be attained in four-weeks (Clark & Lucett, 2011). Accordingly, these participants were required to individually complete a minimum of three of these training sessions per week in order to remain compliant with the intervention protocol throughout the four-week intervention.

Intervention compliance. In order to assess compliance, participants were given a written weekly Compliance Questionnaire (Appendix J) that assessed their intervention compliance by monitoring what days of the week they performed their corrective exercise programming and estimated the amount of time they spent completing these training sessions. These questionnaires were collected at the end of the study.

Corrective exercise program prescription. The four-week corrective exercise programs prescribed in this intervention consisted of the exercises recommended by the Fusionetics software. This software was developed from the corrective exercise principles created by the National Academy of Sports Medicine (NASM) and outlined in the *NASM Essentials of Corrective Exercise Training* textbook (Clark & Lucett, 2011). These corrective exercises are prescribed by the Fusionetics software in an attempt to restore optimal neuromuscular control and correct any neuromuscular imbalances that the individual displayed during their respective ME Test. Specifically, these corrective exercises attempt to address the individual's underlying neuromuscular deficiencies, and consequently, improve their functional movement quality by accomplishing the following goals: (a) increasing dynamic range of motion (ROM) by inhibiting overactive muscular and lengthening tight musculature; (b) increasing

neuromuscular strength by activating underactive musculature; and (c) integrating this newly created ROM and neuromuscular strength by performing functional exercises that incorporate dynamic movements (Clark & Lucett, 2011).

As such, based on the NASM corrective exercise principles, these corrective exercises were performed in the following specific sequence during each corrective exercise session: (1) inhibit overactive muscles; (2) lengthen tight muscles; (3) strengthen weak muscles; and (4) perform dynamic integration exercises. An example of a CEP sequence prescribed for dynamic knee valgus is provided in Table 2 (adapted from Bell et al., 2013).

Table 2

Example of Corrective Exercises Prescribed for Dynamic Knee Valgus

Exercise Sequence	Targeted Musculature	Prescribed Exercises
1. Inhibit Overactive Muscles	Gastrocnemius / Soleus; Lateral Hamstring	Slowly foam roll each muscle for two min
2. Lengthen Tight Muscles	Gastrocnemius / Soleus; Lateral Hamstring	Static stretch: 2 sets × 30-sec holds
3. Strengthen Weak Muscles	Medial Gastrocnemius; Medial Hamstring; Tibialis Posterior / Anterior; Medial Gluteal	Slowly controlled calf raises (4-sec eccentric, 1-sec concentric) off a step; resisted dorsiflexion with elastic bands (2 sets × 8-10 reps each)
4. Integration Exercises		Single-leg balance reaches, single-leg squats, single leg hops (1 set × 10-15 reps each)

Note. Adapted from "Two-and 3-dimensional knee valgus are reduced after an exercise intervention in young adults with demonstrable valgus during squatting" by D.R. Bell, D.C., Oates, M.A., Clark, & D.A. Padua, 2013, *Journal of Athletic Training*, *48*(4), p. 445.

The number of repetitions (reps) and sets (i.e., intensity) of these corrective exercises were indicated to the participant in the Fusionetics software. In order to stimulate a physiological overload (Kraemer & Ratamess, 2004), the intensity of this corrective exercise

programming was progressed throughout the four-weeks as described in Table 3. This progression was held constant across all participants.

Table 3

Exercise Intensity Progression

Exercise	Week 1	Week 2	Week 3	Week 4
Self-Myofascial Release	1 set, 30 sec	1 sets, 30 sec	1 set, 30 sec	1 set, 30 sec
Static Stretching	1 set, 30 sec	2 sets, 30 sec	2 sets, 30 sec	2 sets, 30 sec
Isolated Strengthening	1 set, 10 reps	2 sets, 10 reps	2 sets, 15 reps	2 sets, 15 reps
Integration	1 set, 10 reps	2 sets, 10 reps	2 sets, 15 reps	2 sets, 15 reps

Other concurrent exercise programming. Participants were also instructed to maintain any other structured exercise programming in which they were already engaged in (i.e., aerobic exercise, resistance exercise, etc.). However, they were instructed to not progress the intensity or volume of this other exercise training during the four-week intervention. If a participant wished to complete both the corrective exercise programming and exercises associated with their other concurrent training (e.g., running, weight training, etc.) on the same day, they were instructed to complete these other additional exercise after the exercises associated with the corrective exercise program (i.e., complete the corrective exercises first). In addition, all participants completed an Exercise History Questionnaire that assessed their current level of exercise and the exercise modalities they utilize (Appendix K).

Data Management

All hardcopy records of the anthropometric, functional movement, health and fitness data, and various questionnaires were stored in locked file cabinets in the HPSPL on the UWM

campus (3409 N. Downer Avenue, Milwaukee, WI 53211). All electronic ME Test score data was stored on the Fusionetics online platform so each participant had access to their own ME Test score data and their respective corrective exercise programs.

Staffing

The primary researcher of the current study had previous experience with the collection of all measures utilized in the current study, as well as the statistical methodology required. In addition, this researcher held current automated external defibrillator (AED) and cardiopulmonary resuscitation (CPR) certifications through the American Red Cross. Furthermore, this researcher held various health and fitness certifications through professional organizations. These certifications are recognized by the National Commission for Certifying Agencies (NCCA) and included: Certified Strength & Conditioning Specialist (CSCS) and Tactical Strength and Conditioning – Facilitator (TSAC-F) through the National Strength and Conditioning Association (NSCA); certified Corrective Exercise Specialist (CES) through the NASM; and Certified Exercise Physiologist (EP-C) through the ACSM. As such, the primary researcher of the current study had the expertise and competencies required to collect all anthropometric, functional movement, and health and fitness data.

Statistical Analyses

All *a priori* power analyses ($1–\beta$) were conducted using G*Power 3.1.9.2 software (Heinrich-Heine-Universitat Dusseldorf). All *post hoc* statistical analyses were conducted using IBM SPSS 22 software (IBM Corp., Armonk, NY). Due to the exploratory nature of the current study, an alpha level of .05 was utilized to determine statistical significance for all analyses. Effect sizes were evaluated using partial eta squared test statistics (η^2_p), with $\eta^2_p < .06$, $.06 \leq \eta^2_p < .14$, and $.14 \leq \eta^2_p$ indicating a small, medium, and large effect, respectively (Huck, 2012).

Specific Aim #1. The influence of targeted corrective exercise program intervention on functional movement (i.e., Total FMS and Overall ME Test scores) among active-duty firefighters was examined by utilizing two separate within-between repeated measures analyses of variance (RM ANOVAs). Specifically, the potential 2 × 3 interaction effect between Group (CON, CEP) and Time (Week 0, 3, 5) on both Total FMS score and Overall ME Test score will be examined. In the event a significant 2 × 3 interaction effect was identified, follow-up simple effects of the Group (CON, CEP) between-subjects factor at each level of Time (Week 0, 3, 5) within-subjects factor were examined. If a significant 2 × 3 interaction effect is not identified, the main effects of the Time (Week 0, 3, 5) within-subjects factor were examined and follow-up pairwise analyses were utilized.

In addition, these statistical analyses were performed by utilizing the completers analysis approach (Portney & Watkins, 2009). Specifically, in the event of a participant dropout due to no-show ($n = 2$) or injury ($n = 2$), data associated with these participants were eliminated when conducting the RM ANOVAs associated with Specific Aim #1.

Hypotheses**.** It was hypothesized that a four-week corrective exercise program intervention would significantly improve functional movement quality among active-duty firefighters. Specifically, it was hypothesized that a significant interaction effect between Group and Time would be identified. Furthermore, was also hypothesized that significant simple effects of the Group (between) factor at Weeks 3 and 5 would be identified and that individuals in the CEP group would demonstrate significantly greater levels of functional movement (i.e., Total FMS & Overall ME Test scores) when compared to the CON group. This would imply that corrective exercise program interventions were capable of eliciting significant improvements in functional movement quality among active-duty firefighters, and thus, a short-term corrective

exercise program may significantly decrease the risk of future MSKI in this population and future prospective research would be warranted.

***Power analysis*.** An *a priori* power analysis (Beck, 2013) utilizing a medium effect size (f = .25), two groups (CON & CEP Groups), and three testing measurements (Weeks 0, 3, 5), revealed a total sample size of 28 was required to achieve a power of $1- \beta$ = .80 for each within-between RM ANOVA in Specific Aim #1.

***Covariates*.** Previous research has identified a significant relationship between functional movement and age (Loudon et al., 2014; Perry & Koehle, 2013; Teyhen et al., 2014b), as well as the significant relationship between functional movement and obesity-level (Duncan & Stanley, 2012; Duncan, Stanley, & Wright, 2013; Perry & Koehle, 2013), including among the firefighter population (Cornell, Gnacinski, Zamzow, Mims, & Ebersole, in press[a]). As such, exploratory bivariate Pearson correlations (r) were conducted between the measures of functional movement (i.e., Total FMS & Overall ME Test scores) and age (yrs) and the measures of functional movement (i.e., Total FMS & Overall ME Test scores) and BMI (kg/m^2), that were collected during Phase 1 (Week 0) of this study. Since a significant relationship was identified between age and Total FMS score (r = -.492, p < .001), the continuous variable of age was utilized as a covariate in this RM ANOVA (i.e., a RM ANCOVA). However, since a significant relationship was not identified between age and Overall ME Test score (r = -.177, p = .231), nor between BMI and Total FMS score or Overall ME Test score (r = -.159, p = .265; r = -.195, p = .170, respectively), these measures were not utilized as covariates in these respective RM ANOVAs.

Specific Aim #2. The influence of the targeted corrective exercise program intervention on measures of health and fitness among active-duty firefighters was examined by utilizing three separate RM ANOVAs. Specifically, the potential 2 × 2 interaction effect between Group

(CON, CEP) and Time (Week 0, 5) on each health and fitness measure of interest (i.e., peak CMJ height, isometric $1RM_{Deadlift}$, & $Plank_{max}$ time) was examined.

In addition, these statistical analyses were performed by utilizing the completers analysis approach (Portney & Watkins, 2009). Specifically, in the event of a participant dropout due to no-show (n = 2) or injury (n = 2), data associated with these participants were eliminated when conducting the RM ANOVAs associated with Specific Aim #2.

***Hypotheses*.** It was hypothesized that a targeted corrective exercise program intervention would significantly improve the health and fitness measures of interest (i.e., peak CMJ height, estimated $1RM_{Squat}$, & $Plank_{max}$ time). This would imply that the targeted corrective exercise program interventions were capable of improving measures of general health and fitness among active-duty firefighters.

***Power analysis*.** An *a priori* power analysis (Beck, 2013) utilizing a medium effect size (f = .25), two groups (CON & CEP Groups), and two testing measurements (Weeks 0 & 5), revealed a total sample size of 34 was required to achieve a power of $1–\beta$ = .80 for each within-between RM ANOVA in Specific Aim #2.

Specific Aim #3. In order to establish the criterion-reference validity of the Overall ME Test score among active-duty firefighters, the relationship between Total FMS and Overall ME Test scores was examined using Total FMS score as the criterion-reference in relation to Overall ME Test score (Jewell, 2015). Accordingly, a bivariate Pearson correlation (r) was utilized to examine the relationship and measure of common variance (R^2) between the Total FMS score and Overall ME Test score collected during Phase 1 of this study.

***Hypothesis*.** It was hypothesized that a good-to-excellent positive correlation (r = .76 – 1.00), as described by Portney & Watkins (2009), would be identified between Total FMS and

Overall ME Test scores. This would imply that the ME Test has a strong relationship with the already established FMS, thus establishing criterion-reference validity of this new measure of functional movement among the active-duty firefighter population.

Power analysis**.** An *a priori* power analysis utilizing a large hypothesized effect size (ρ = .5) revealed a sample size of 29 was required to achieve a power of $1–\beta$ = .80 for the bivariate Pearson correlation (Faul, Erdfelder, Buchner, & Lang, 2009) utilized in Specific Aim #3.

Chapter IV: Results

Specific Aim #1

Specific Aim #1 of the current study examined the influence of a four-week corrective exercise program intervention on measures of functional movement among active-duty firefighters through the use of a quasi-experimental design. Functional movement was quantified using the Functional Movement Screen (FMS) and the Movement Efficiency (ME) Test associated with the Fusionetics Human Performance System (Total FMS score & Overall ME Test score, respectively). Participants were placed into either the Corrective Exercise Program (CEP) group or the Control (CON) group in a counterbalanced fashion, based on their respective Overall ME Test score. Participants in the CEP group (n = 27) were given a four-week corrective exercise programming intervention and the four-week corrective exercise programming intervention for the participants in the CON group (n = 24) was deferred for four-weeks (i.e., a deferred treatment protocol). It was hypothesized that a four-week corrective exercise program intervention would significantly improve functional movement quality among active-duty firefighters.

Participants. Due to the elimination of two female participants, two participants who sustained an injury, two participants who did not show up for data collection, and one non-compliant participant, a total of seven participants were eliminated from the statistical analyses utilized in Specific Aim #1 resulting in a total sample population of 44 participants. Descriptive mean ± standard deviation (*SD*) data of this sample population can be found in Table 4.

Table 4

Specific Aim #1: Participant Descriptive Data – Functional Movement Quality

Age (yrs)	Mean	*SD*	Range
Total (*N* = 44)	40.5	7.7	28 – 59
CON (*n* = 22)	40.5	8.5	29 – 59
CEP (*n* = 22)	40.5	7.1	28 – 52
Height (cm)	Mean	*SD*	Range
Total (*N* = 44)	179.8	5.3	169.0 – 191.0
CON (*n* = 22)	180.1	4.7	171.5 – 188.0
CEP (*n* = 22)	179.6	6.0	169.0 – 191.0
Weight (kg)	Mean	*SD*	Range
Total (*N* = 44)	91.1	8.6	73.9 – 106.8
CON (*n* = 22)	92.2	8.6	76.8 – 106.8
CEP (*n* = 22)	90.1	8.7	73.9 – 104.1
BMI (kg/m^2)	Mean	*SD*	Range
Total (*N* = 44)	28.2	2.6	23.8 – 35.6
CON (*n* = 22)	28.4	2.6	24.5 – 35.3
CEP (*n* = 22)	27.9	2.6	23.8 – 35.6

Note: yrs, years; cm, centimeters; kg, kilograms; m^2, meters squared; BMI, body mass index.

Total FMS score. Visual inspections of the data and normal P-P plots revealed no consistent outliers across the Total FMS score variable. In addition, skewness and kurtosis values of the Total FMS score variable indicated a normal distribution of the data (Table 5). However, the Mauchly's Test of Sphericity indicated a violation of the assumption of sphericity in the data (Mauchly's $W(2) = 0.843$, $p = .033$). As such, a Greenhouse-Geisser correction was utilized for the repeated measures analyses of covariance (RM ANCOVA) test.

Table 5

Specific Aim #1: Total FMS Score – Data Distribution Statistics

Time	Variance	Skewness		Kurtosis	
		Statistic	Error	Statistic	Error
Week 0	9.5	0.501	0.357	-0.612	0.702
Week 3	5.2	0.831	0.357	1.257	0.702
Week 5	5.9	0.876	0.357	1.084	0.702

Independent samples *t* tests indicated no statistically significant differences in Total FMS scores between City of Milwaukee Fire Department (MFD) and North Shore Fire Department (NSFD) participants ($t(42) = -0.205$, $p = .839$; $t(42) = 0.154$, $p = .878$; $t(42) = -0.116$, $p = .908$, respectively) at Week 0, Week 3, or Week 5 (12.3 ± 3.2 vs. 12.5 ± 2.8; 12.9 ± 2.4 vs. 12.8 ± 1.7; 13.1 ± 2.5 vs. 13.3 ± 2.1, respectively).

Results. Results of the 2 × 3 within-between RM ANCOVA, with the continuous variable of age (yrs) used as a covariate, indicated a statistically significant and medium interaction effect between the Time and Group factors ($F(1.728,70.861) = 6.114$, $p = .005$, $\eta^2_p = .130$). However, follow-up tests for simple effects identified no statistically significant differences between the CON and CEP groups at Weeks 0, 3, or 5 ($F(1,41) = 1.944$, $p = .171$, $\eta^2_p = .045$; $F(1,41) = 0.009$, $p = .924$, $\eta^2_p < .001$; $F(1,41) = 0.320$, $p = .575$, $\eta^2_p = .008$, respectively). Furthermore, when split by groups, a statistically significant main effect of Time was not identified in either the CON or the CEP groups as well ($F(2,40) = 1.408$, $p = .257$, $\eta^2_p = .066$; $F(2,40) = 0.800$, $p = .446$, $\eta^2_p = .038$, respectively). These results suggest that even though a significant interaction effect was identified, there were no statistically significant differences in Total FMS scores between the CON and CEP groups pre, mid, or post (12.9 ± 3.1 vs. 11.7 ± 3.2;

13.0 ± 2.2 vs. 12.8 ± 2.4; 13.0 ± 1.9 vs. 13.4 ± 2.9, respectively) the four-week corrective exercise intervention (Figure 5).

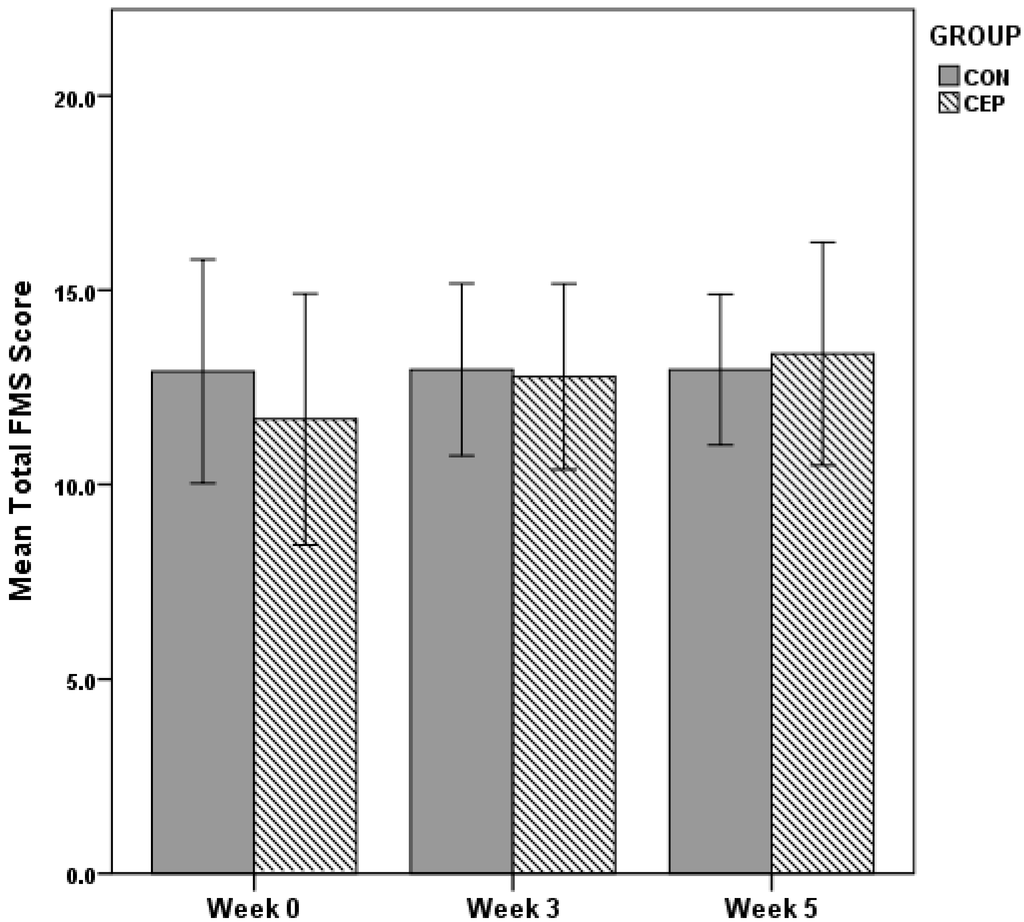

Figure 5. Specific Aim #1: Total FMS scores across time. Data are represented as mean ± *SD*.

Overall ME Test score. Visual inspections of the data and normal P-P plots revealed no consistent outliers across the Overall ME Test score variable and the skewness and kurtosis values indicated a normal distribution of the data (Table 6). In addition, the Mauchly's Test of Sphericity confirmed the assumption of sphericity in the data (Mauchly's $W(2) = 0.952$, $p = .367$).

Table 6

Specific Aim #1: Overall ME Test Score – Data Distribution Statistics

Time	Variance	Skewness		Kurtosis	
		Statistic	Error	Statistic	Error
Week 0	167.3	0.321	0.357	-0.558	0.702
Week 3	145.3	0.045	0.357	-0.549	0.702
Week 5	147.0	0.462	0.357	0.271	0.702

Independent samples *t* tests indicated no statistically significant differences in Overall ME Test scores between MFD and NSFD participants ($t(42) = 0.773$, $p = .444$; $t(42) = -1.145$, $p = .154$; $t(42) = -0.762$, $p = .450$, respectively) at Week 0, Week 3, or Week 5 (45.14 ± 12.57 vs. 41.21 ± 14.97; 45.21 ± 11.21 vs. 51.97 ± 14.91; 45.52 ± 11.44 vs. 49.15 ± 15.36, respectively).

Results. Based on the results of the 2 × 3 within-between RM ANOVA, a statistically significant interaction effect between the Time and Group factors was not identified ($F(2,84) = 1.550$, $p = .218$, $\eta^2_p = .036$). In addition, a statistically significant main effect of Time was not identified ($F(2,84) = 0.982$, $p = .379$, $\eta^2_p = .023$). Furthermore, when split by groups, a statistically significant main effect of Time was not identified in either the CON or the CEP groups as well ($F(2,42) = 0.449$, $p = .641$, $\eta^2_p = .021$; $F(2,42) = 2.416$, $p = .102$, $\eta^2_p = .103$, respectively). These results suggest that were no statistically significant differences in Overall ME Test scores between the CON and CEP groups, as well as within each group, pre, mid, or post (46.41 ± 12.74 vs. 42.43 ± 13.12; 47.78 ± 11.21 vs. 45.10 ± 12.97; 45.53 ± 12.56 vs. 46.83 ± 11.93, respectively) the four-week corrective exercise intervention (Figure 6).

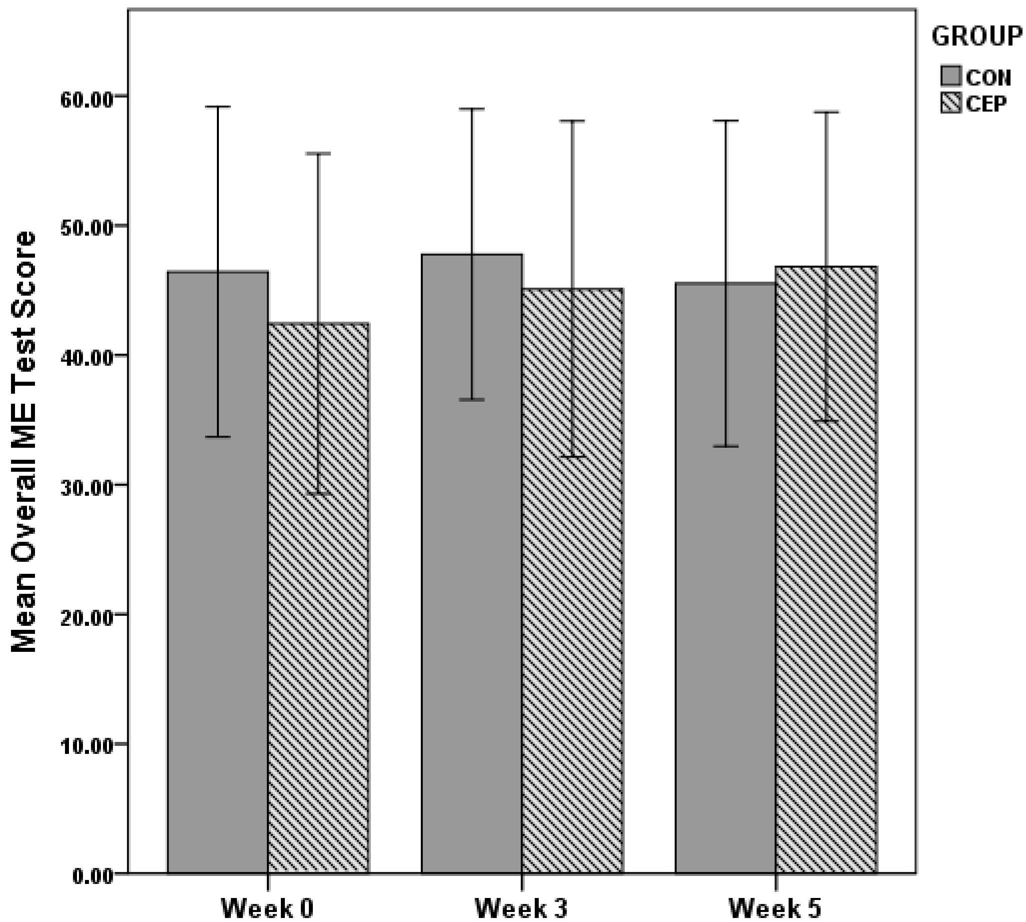

Figure 6. Specific Aim #1: Overall ME Test scores across time. Data are represented as mean ± *SD*.

Specific Aim #2

Specific Aim #2 of the current study examined the influence of a four-week corrective exercise program intervention on measures of health and fitness among active-duty firefighters through the use of a quasi-experimental design. These health and fitness measures have been previously associated with functional movement quality among the firefighter population and are included in the already implemented The Fire Service Joint Labor Management Wellness-Fitness Initiative (WFI) created by the International Association of Fire Fighters (IAFF) and the

International Association of Fire Chiefs (IAFC) (International Association of Fire Fighters, 2008).

Total body power output. Total body power output was quantified as countermovement jump (CMJ) height in cm.

***Participants*.** Due to the elimination of two female participants, two participants who sustained an injury, two participants who did not show up for data collection, and one non-compliant participant, a total of seven participants were eliminated from all statistical analyses utilized in Specific Aim #2. In addition, the CMJ data of one participant in the CON group was also lost due to equipment complications, resulting in a total sample size of 21 participants in this group. Descriptive mean ± *SD* data of this sample population can be found in Table 7.

Table 7

Specific Aim #2: Participant Descriptive Data – Total Body Power Output

Age (yrs)	Mean	*SD*	Range
Total (*N* = 43)	40.4	7.8	28 – 59
CON (*n* = 21)	40.3	8.7	29 – 59
CEP (*n* = 22)	40.5	7.1	28 – 52
Height (cm)	Mean	*SD*	Range
Total (*N* = 43)	179.9	5.4	169.0 – 191.0
CON (*n* = 21)	180.2	4.7	171.5 – 188.0
CEP (*n* = 22)	179.6	6.0	169.0 – 191.0
Weight (kg)	Mean	*SD*	Range
Total (*N* = 43)	90.9	8.6	73.9 – 106.8
CON (*n* = 21)	91.8	8.6	76.8 – 106.8
CEP (*n* = 22)	90.1	8.7	73.9 – 104.1
BMI (kg/m^2)	Mean	*SD*	Range
Total (*N* = 43)	28.1	2.6	23.8 – 35.6
CON (*n* = 21)	28.3	2.6	24.5 – 35.3
CEP (*n* = 22)	27.9	2.6	23.8 – 35.6

Assumptions. Visual inspections of the data and normal P-P plots revealed no consistent outliers across the CMJ height variable and the skewness and kurtosis values indicated a normal distribution of the data (Table 8). In addition, Levene's Test of Equality of Variances confirmed the assumption of homogeneity of variances in the CMJ height data both at Week 0 and Week 5 ($F(1,41) = 0.040$, $p = .843$; $F(1,41) = 1.806$, $p = .186$, respectively).

Table 8

Specific Aim #2: CMJ Height – Data Distribution Statistics

Time	Variance	Skewness		Kurtosis	
		Statistic	Error	Statistic	Error
Week 0	73.7	1.057	0.361	1.523	0.709
Week 5	60.0	1.212	0.361	2.673	0.709

Independent samples *t* tests indicated no statistically significant differences in CMJ Height between MFD and NSFD participants ($t(41) = -0.296$, $p = .769$; $t(41) = -0.436$, $p = .665$, respectively) at Week 0 or Week 5 (44.7 ± 9.2 vs. 45.8 ± 5.8; 38.4 ± 8.2 vs. 39.7 ± 5.0, respectively).

Results. Based on the results of the 2 × 2 within-between RM ANOVA, a statistically significant and large interaction effect between the Time and Group factors was identified ($F(1,41) = 10.189$, $p = .003$, $\eta^2_p = .199$). However, follow-up tests for simple effects identified no significant differences between the CON and CEP groups at Weeks 0 or 5 ($F(1,41) = 0.136$, $p = .714$, $\eta^2_p = .003$; $F(1,41) = 0.280$, $p = .599$, $\eta^2_p = .007$, respectively). These results suggest that even though a significant interaction effect was identified, there were no statistically significant differences in CMJ height between the CON and CEP groups pre or post the four-week corrective exercise intervention (Table 9).

Due to the lack of a statistically significant simple effects, the main effect of Time was examined. Results of this analysis identified a statistically significant and large main effect of Time ($F(1,41) = 325.074$, $p < .001$, $\eta^2_p = .888$). Furthermore, when split by group, a statistically significant and large main effect of Time was also identified among both CON and CEP groups ($F(1,20) = 158.356$, $p < .001$, $\eta^2_p = .888$; $F(1,21) = 179.210$, $p < .001$, $\eta^2_p = .885$, respectfully).

This suggests that irrespective of group membership, the CMJ height significantly decreased pre to post the four-week corrective exercise intervention (Table 9).

Table 9

Specific Aim #2: CMJ Height (cm) Across Time

Week 0	Mean	*SD*	Range
Total (*N* = 43)	44.9	8.6	29.7 – 72.6
CON (*n* = 21)	45.4	7.8	34.4 – 63.7
CEP (*n* = 22)	44.5	9.4	29.7 – 72.6
Week 5	**Mean**	***SD***	**Range**
Total (*N* = 43)	38.7*	7.7	24.0 – 66.0
CON (*n* = 21)	38.0#	6.1	27.9 – 52.0
CEP (*n* = 22)	39.3†	9.0	24.0 – 66.0

Note: *statistically significant decrease from Week 0 to Week 5 among all participants ($p < .05$); #statistically significant decrease from Week 0 to Week 5 among CON group ($p < .05$); †statistically significant decrease from Week 0 to Week 5 among CEP group ($p < .05$).

Lower extremity muscular strength. Lower extremity muscular strength was quantified as one-repetition maximal isometric deadlift ($1RM_{Deadlift}$) in kg normalized to bodyweight (kg/kg).

***Participants*.** Due to the elimination of two female participants, two participants who sustained an injury, two participants who did not show up for data collection, and one non-compliant participant, a total of seven participants were eliminated from all statistical analyses utilized in Specific Aim #2. In addition, due to equipment limitations, Week 5 measures of $1RM_{Deadlift}$ were not collected among all NSFD participants, and thus, data from eight additional participants were eliminated, resulting in a total sample population of 36 participants. Descriptive mean ± *SD* data of this sample population can be found in Table 10.

Table 10

Specific Aim #2: Participant Descriptive Data – Lower Extremity Muscular Strength

Age (yrs)	Mean	*SD*	Range
Total (N = 36)	41.1	8.1	28 – 59
CON (n = 18)	41.4	8.8	29 – 59
CEP (n = 18)	40.8	7.7	28 – 52
Height (cm)	Mean	*SD*	Range
Total (N = 36)	179.7	5.1	169.0 – 191.0
CON (n = 18)	180.0	4.9	171.5 – 188.0
CEP (n = 18)	179.4	5.8	169.0 – 191.0
Weight (kg)	Mean	*SD*	Range
Total (N = 36)	91.3	8.9	73.9 – 106.8
CON (n = 18)	92.4	8.7	76.8 – 106.8
CEP (n = 18)	90.2	9.3	73.9 – 104.1
BMI (kg/m^2)	Mean	*SD*	Range
Total (N = 36)	28.3	2.8	23.8 – 35.6
CON (n = 18)	28.5	2.8	24.5 – 35.3
CEP (n = 18)	28.0	2.8	23.8 – 35.6

Assumptions. Visual inspections of the data and normal P-P plots revealed no consistent outliers across the $1RM_{Deadlift}$ variable and the skewness and kurtosis values indicated a normal distribution of the data (Table 11). In addition, Levene's Test of Equality of Variances confirmed the assumption of homogeneity of variances in the $1RM_{Deadlift}$ data both at Week 0 and Week 5 ($F(1,34) = 0.402$, $p = .530$; $F(1,34) = 0.070$, $p = .793$, respectively).

Table 11

Specific Aim #2: $1RM_{Deadlift}$ – Data Distribution Statistics

Time	Variance	Skewness		Kurtosis	
		Statistic	Error	Statistic	Error
Week 0	0.124	0.071	0.393	-0.471	0.768
Week 5	0.118	0.302	0.393	-0.005	0.768

Results. Based on the results of the 2 × 2 within-between RM ANOVA, a statistically significant interaction effect between the Time and Group factors was not identified ($F(1,34) = 0.139$, $p = .712$, $\eta^2_p = .004$). In addition, a statistically significant main effect of Time was not identified ($F(1,34) = 0.623$, $p = .435$, $\eta^2_p = .018$). Furthermore, when split by groups, a statistically significant main effect of Time was not identified in either the CON or the CEP groups as well ($F(1,17) = 0.504$, $p = .487$, $\eta^2_p = .029$; $F(1,17) = 0.131$, $p = .721$, $\eta^2_p = .008$, respectively). These results suggest that were no statistically significant differences in $1RM_{Deadlift}$ between the CON and CEP groups, as well as within each group, pre or post the four-week corrective exercise intervention (Table 12).

Table 12

Specific Aim #2: $1RM_{Deadlift}$ (kg/kg) Across Time

Week 0	Mean	*SD*	Range
Total (*N* = 36)	1.50	0.35	0.88 – 2.23
CON (*n* = 18)	1.54	0.32	0.95 – 2.02
CEP (*n* = 18)	1.46	0.38	0.88 – 2.23
Week 5	Mean	*SD*	Range
Total (*N* = 36)	1.52	0.34	0.83 – 2.27
CON (*n* = 18)	1.57	0.34	0.83 – 2.26
CEP (*n* = 18)	1.47	0.34	0.96 – 2.27

Core muscular endurance. Core muscular endurance was quantified as maximal prone plank time ($Plank_{max}$) in seconds (sec).

***Participants*.** Due to the elimination of two female participants, two participants who sustained an injury, two participants who did not show up for data collection, and one non-compliant participant, a total of seven participants were eliminated from all statistical analyses utilized in Specific Aim #2 resulting in a total sample population of 44 participants. Descriptive mean ± *SD* data of this sample population can be found previously in Table 4.

***Assumptions*.** Visual inspections of the data and normal P-P plots revealed no consistent outliers across the $Plank_{max}$ variable and the skewness and kurtosis values indicated a normal distribution of the data (Table 13). In addition, Levene's Test of Equality of Variances confirmed the assumption of homogeneity of variances in the $Plank_{max}$ data both at Week 0 and Week 5 ($F(1,42) = 0.302$, $p = .860$; $F(1,42) = 0.369$, $p = .547$, respectively).

Table 13

Specific Aim #2: $Plank_{max}$ – Data Distribution Statistics

Time	Variance	Skewness		Kurtosis	
		Statistic	Error	Statistic	Error
Week 0	3504.7	0.919	0.357	0.770	0.702
Week 5	4145.8	0.686	0.357	0.368	0.702

Independent samples *t* tests indicated no statistically significant differences in $Plank_{max}$ between MFD and NSFD participants ($t(42) = 0.242$, $p = .810$; $t(42) = 0.250$, $p = .804$, respectively) at Week 0 or Week 5 (147.8 ± 62.1 vs. 142.1 ± 47.2; 172.4 ± 65.8 vs. 166.0 ± 61.4, respectively).

Results. Based on the results of the 2 × 2 within-between RM ANOVA, a statistically significant interaction effect between the Time and Group factors was not identified ($F(1,42) = 0.617$, $p = .437$, $\eta^2_p = .014$). However, a statistically significant and large main effect of Time was identified across all participants ($F(1,42) = 11.618$, $p = .001$, $\eta^2_p = .217$). This implies that when collapsed across both groups, the $Plank_{max}$ time significantly increased from Week 0 to Week 5 (Table 14).

Furthermore, although further analysis revealed a statistically significant main effect of Time in the CEP group ($F(1,21) = 11.550$, $p = .003$, $\eta^2_p = .355$), and a statistically significant main effect of Time was not identified in the CON group ($F(1,21) = 2.777$, $p = .110$, $\eta^2_p = .117$), the lack of a significant interaction effect implies that the mean Week 5 $Plank_{max}$ time of the CEP group was not in fact significantly different than the mean Week 5 $Plank_{max}$ time of the CON group (161.5 vs. 181.0, respectively). As such, these results suggest that familiarization to the

prone plank test itself may result in a significantly improved $Plank_{max}$ time, regardless of a corrective exercise program intervention.

Table 14

Specific Aim #2: $Plank_{max}$ (sec) Across Time

Week 0	Mean	*SD*	Range
Total (*N* = 44)	146.8	59.2	41.0 – 301.0
CON (*n* = 22)	162.1	54.4	90.0 – 298.0
CEP (*n* = 22)	131.4	61.0	41.0 – 301.0
Week 5	**Mean**	***SD***	**Range**
Total (*N* = 44)	171.2*	64.4	46.0 – 352.0
CON (*n* = 22)	181.0	68.3	90.0 – 352.0
CEP (*n* = 22)	161.5†	60.2	46.0 – 270.0

Note: *statistically significant increase from Week 0 to Week 5 among all participants ($p < .05$); †statistically significant increase from Week 0 to Week 5 among CEP group ($p < .05$).

Specific Aim #3

Specific Aim #3 of this study examined the criterion-reference validity of the Overall ME Test score, in relation to the Total FMS score, among active-duty firefighters. It was hypothesized that a good-to-excellent positive correlation ($r = .76 – 1.00$), as described by Portney and Watkins (2009), would be identified between Total FMS and Overall ME Test scores that were collected during Week 0 (i.e., Phase 1) of the study. If a good-to-excellent positive correlation were identified, this would imply that the ME Test has a strong relationship with the already established FMS, thus establishing criterion-reference validity of this new measure of functional movement among the active-duty firefighter population.

Participants. Due to the elimination of female participants, a total of two participants were eliminated from the statistical analyses utilized in Specific Aim #3, resulting in a total sample population of 49 participants. Descriptive mean ± *SD* data of this sample population can be found in Table 15.

Table 15

Specific Aim #3: Participant Descriptive Data

Variable (*N* = 49)	Mean	*SD*	Range
Age (yrs)	40.7	7.9	28 – 59
Height (cm)	179.2	5.5	169.0 – 191.0
Weight (kg)	90.8	9.1	73.8 – 108.6
BMI (kg/m^2)	28.3	2.8	23.8 – 35.6

Assumptions. Visual inspections of the data and normal Q-Q plots revealed no consistent outliers across the Total FMS score and Overall ME Test score variables and the skewness and kurtosis values indicated a normal distribution of the data (Table 16).

Table 16

Specific Aim #3: Data Distribution Statistics

Time	Variance	Skewness		Kurtosis	
		Statistic	Error	Statistic	Error
Total FMS Score	9.02	0.514	0.340	-0.541	0.668
Overall ME Test Score	157.53	0.251	0.340	-0.526	0.668

Results. Mean ± *SD* descriptive data of the Total FMS score and Overall ME Test score data can be found in Table 17. Independent samples *t* tests indicated no statistically significant

differences in Total FMS scores or Overall ME Test scores ($t(47) = -0.585$, $p = .561$; $t(47) = 0.598$, $p = .553$, respectively) between MFD and NSFD participants (12.1 ± 3.1 vs. 12.8 ± 2.8; 45.34 ± 12.17 vs. 42.56 ± 14.58, respectively).

Table 17

Specific Aim #3: Descriptive Functional Movement Quality Data

Variable (N = 49)	Mean	*SD*	Range
Total FMS Score	12.24	3.00	8 – 19
Overall ME Test Score	44.83	12.53	19.67 – 72.28

Results of the bivariate Pearson correlation analysis identified a statistically significant and direct correlation between Total FMS score and Overall ME Test score ($r = .634$, $p < .001$, 95% CI = 0.430 – 0.776). The results of this correlation suggest that a moderate-to-good relationship, as described by Portney and Watkins (2009), exists between the newly developed ME Test and the already established FMS (Figure 7). However, these results also suggest that the Overall ME Test score only explains roughly 40.3% of the variance of the Total FMS score ($R^2 = .403$). As such, even though a statistically significant relationship exists between these two functional movement assessments, the ME Test may lack criterion-reference validity in relation to the FMS among the population of active-duty firefighters (Jewell, 2015). Therefore, the ME Test may fundamentally measure functional movement quality differently than the FMS among this cohort population.

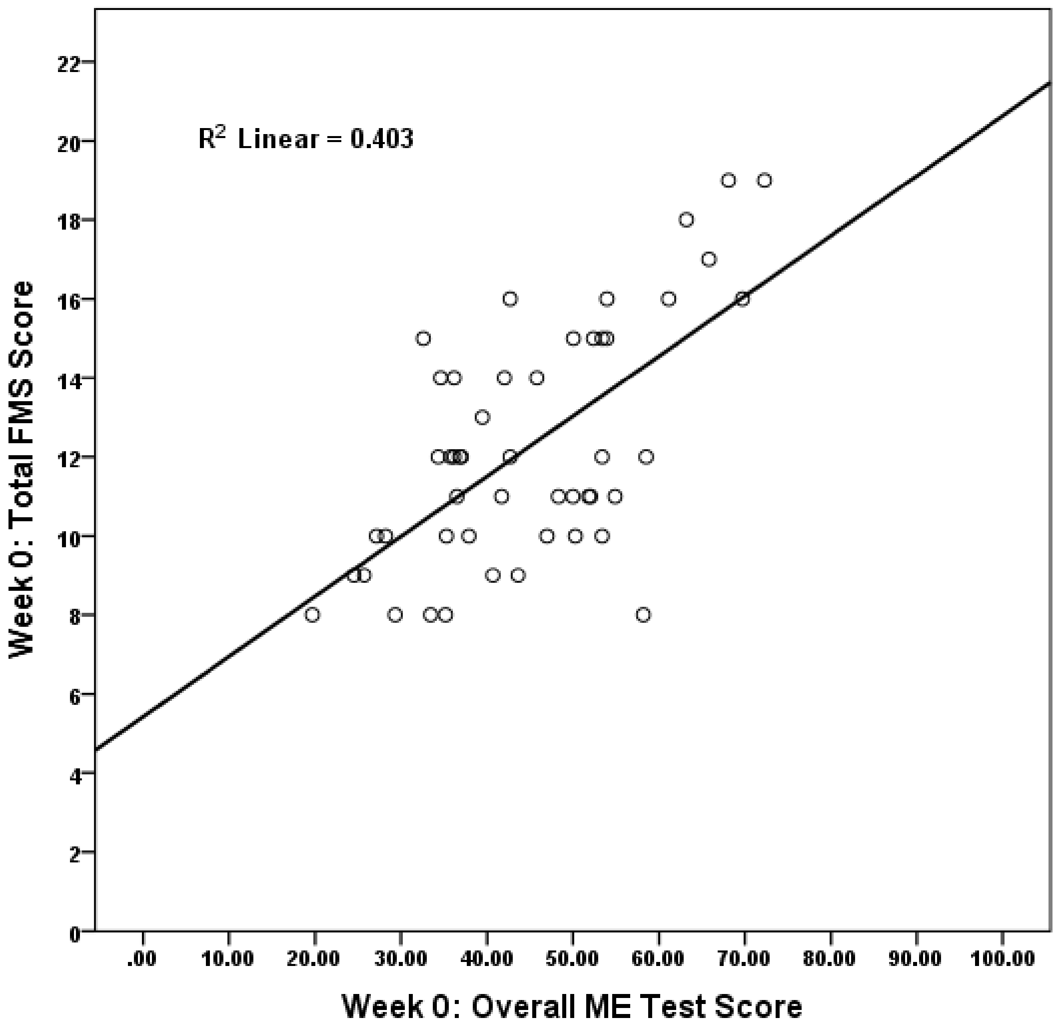

Figure 7. Criterion-reference validity of the ME Test.

Chapter V: Discussion

Specific Aim #1

Introduction. The primary aim of this study was to examine the influence of a four-week corrective exercise program intervention on measures of functional movement quality among active-duty firefighters. Functional movement quality was quantified using the Functional Movement Screen (FMS) total score and the Movement Efficiency (ME) Test associated with the Fusionetics Human Performance System (Total FMS score & Overall ME Test score, respectively). Forty-four participants completed the intervention portion of the study and were placed into either the Corrective Exercise Program (CEP) group (n = 22) or the Control (CON) group (n = 22) in a counterbalanced fashion based on their initial (Week 0) Overall ME Test score. It was hypothesized that a four-week corrective exercise program intervention would significantly improve functional movement quality among active-duty firefighters.

Total FMS score. This study determined that although the Total FMS scores of participants in the CEP group increased as a result of the four-week corrective exercise program intervention (i.e., from Week 0 to Week 5), these Total FMS scores at week 5 were not significantly different than those demonstrated by the CON group at the end of the intervention (13.0 ± 1.9 vs. 13.4 ± 2.9, respectively). This implies that the four-week corrective exercise program did not significantly improve the functional movement quality of the participants in relation to the CON group (Figure 5). Based on the working hypothesis that functional movement quality is related to musculoskeletal injury (MSKI) risk (Cook, Burton, Hoogenboom, & Voight, 2014a; Cook, Burton, Hoogenboom, & Voight, 2014b), the ability of this corrective exercise programming to reduce potential MSKI risk remains unclear.

The results of the current study differ from previous interventions described in the literature that have demonstrated improvements in Total FMS scores among both traditional athlete populations (Bodden, Needham, & Chockalingam, 2015; Kiesel, Plisky, & Butler, 2011), as well as tactical athlete populations (Cowen, 2010; Goss, Christopher, Faulk, & Moore, 2009). However, it is important to note that none of these previous studies that have identified significant improvements in Total FMS scores after their respective interventions have utilized a control group in their investigations. In contrast, previous studies that have utilized a control group in their intervention protocols have not identified improvements in Total FMS scores that were significantly different than the control group, suggesting that the corrective exercise intervention was not capable of improving functional movement quality any better than a standard fitness training program (Beach, Frost, McGill, & Callaghan, 2014) or participating in generic sporting activities (Wright, Portas, Evans, & Weston, 2015). When coupled with the results of the current study, the influence of corrective exercise interventions on functional movement quality in the literature should be interpreted with caution. It is possible that differences in the corrective exercise intervention protocols across all prior studies may have contributed, in part, to the lack of agreement between studies. Therefore, future research should examine the influence of specific corrective exercise training protocols or philosophies on Total FMS scores.

Although there was not a statistically significant difference in Total FMS scores between the CEP group and the CON group after the intervention (i.e., Week 5), it is important to note that there were no changes in Total FMS scores across the intervention among CON group participants (12.9; 13.0; 13.0, respectively). In addition, previous unpublished intra-rater reliability research conducted by the primary researcher of the current study suggests that the

minimal detectable difference (*MDD*) of the Total FMS score data is 1.9 (Cornell et al., unpublished laboratory data). Since the participants in the CEP group increased their Total FMS scores by 1.7 from Week 0 to Week 5 (11.7 vs. 13.4), it appears that the change in functional movement quality that the participants in the CEP group demonstrated was approaching a magnitude that could be considered *real*, and thus, clinically meaningful for a practitioner (Jewell, 2015; Weir, 2005). Previous studies that have demonstrated an increase in Total FMS scores utilized an intervention between six and eight weeks in length (Bodden et al., 2015; Kiesel et al., 2011; Cowen, 2010; Goss et al., 2009). In addition, other studies have identified changes in other movement patterns (e.g., a jump-landing) after a three-month injury prevention intervention program (Padua et al., 2012). Thus, it is possible that the four-week corrective exercise program in the current study was simply not a long enough intervention to elicit statistically significant changes in Total FMS scores. As such, future research should examine if a longer corrective exercise intervention is required to elicit both a statistically and clinically meaningful changes in Total FMS scores.

Additionally, it has recently been demonstrated that the deep squat (DS) sub-test score predicts the resulting Total FMS score among collegiate athletes (Clifton, Grooms, & Onate, 2015) and other research has questioned the factorial validity of the shoulder movement (SM), active straight leg raise (ASLR), trunk stability (TS) push-up, and rotary stability (RS) sub-tests (Gnacinski, Cornell, Meyer, Arvinen-Barrow, & Earl-Boehm, in press; Kazman, Galecki, Lisman, Deuster, & O'Connor, 2014; Koehle, Sinnen, Saffer, & MacInnis, 2016; Li, Wang, Chen, & Dai, 2015). It has recently been suggested that the number of FMS sub-tests could be minimized (Clifton et al., 2015; Gnacinski et al., in press) and that some sub-tests may be more influential and/or informative in the prediction of MKSI risk (Bardenett et al., 2015; Hotta et al.,

2015; Tee, Klingbiel, Collins, & Lambert, in press; Warren, Smith, & Chimera, 2015). Therefore, future research should also examine the influence of corrective exercise programming on individual sub-tests of the FMS as well.

***Covariates*.** Preliminary exploratory analyses conducted in the current study also identified a statistically significant correlation between age and Total FMS score (r = -.492, p < .001), which is in agreement with the previous literature as well (Loudon et al., 2014; Perry & Koehle, 2013; Teyhen et al., 2014b). Therefore, the continuous variable of age (years) was utilized as a covariate in the repeated measures analyses of covariance (RM ANCOVA) test. When conducting the analyses without age as a covariate, similar results were observed as a statistically significant and medium interaction effect between the Time and Group factors was identified ($F(1.751,73.541) = 5.232$, $p = .010$, $\eta^2_p = .111$). Follow-up tests for simple effects was again did not identify any statistically significant differences between the CON and CEP groups at Weeks 0, 3, or 5 ($F(1,42) = 1.772$, $p = .190$, $\eta^2_p = .040$; $F(1,42) = 0.069$, $p = .795$, $\eta^2_p = .002$; $F(1,42) = 0.307$, $p = .583$, $\eta^2_p = .007$, respectively). Thus, it is unlikely that age substantially influenced the results observed in the current study.

Other preliminary exploratory analyses conducted in the current study failed to identify a statistically significant correlation between obesity-level, measured as body mass index (BMI), and Total FMS score (r = -.159, p = .265). As such, BMI was not utilized as a covariate in the RM ANCOVAs. This lack of a statistically significant relationship between BMI and Total FMS score differs from other previous research in the literature (Duncan & Stanley, 2012; Duncan, Stanley, & Wright, 2013; Perry & Koehle, 2013), including among the *tactical athlete* population of firefighter recruits (Cornell, Gnacinski, Zamzow, Mims, & Ebersole, in press[a]). Cornell et al. (in press[a]) identified a statistically significant negative correlation between BMI

and Total FMS scores (r = -0.235, p = 0.045), suggesting that obesity-level negatively impacted functional movement quality among firefighter recruits. However, a similar relationship was not identified among this sample population of active-duty firefighters. These results suggest that obesity-level may influence functional movement quality differently between the tactical athlete populations of firefighter recruits and active-duty firefighters.

In addition, although data previously collected by the primary researcher of the current study suggests that the relationship between aerobic fitness and Total FMS score is not statistically significant (r = .163, p = .153) among the firefighter population (Cornell et al., unpublished laboratory data), and a lack of a statistically significant relationship (r = -.03, p > .05) between aerobic fitness and Total FMS score was identified among the military population (Lisman, O'Connor, Deuster, & Knapik, 2013), previous research by Lisman et al. (2013) also suggests that the combination of three-mile run time (i.e., aerobic fitness) and Total FMS score may more effectively predict future MSKI among the military population. As such, it is possible that the current study did not account for a potential influence of aerobic fitness level on the changes in functional movement quality observed during the four-week corrective exercise intervention. Accordingly, future research should also investigate if various anthropometric factors, measures of body composition, and aerobic fitness influences functional movement quality differently between these subset population cohorts.

Overall ME Test score. This study also determined that although the Overall ME Test scores of participants in the CEP group increased as a result of the four-week corrective exercise program intervention (i.e., from Week 0 to Week 5), these Overall ME Test scores for the CEP group were not significantly different than those demonstrated by the CON group at the end of the intervention (45.53 ± 12.56 vs. 46.83 ± 11.93, respectively), nor were the changes in Overall

ME Test scores across time statistically significant among the CEP group participants (42.43 ± 13.12; 45.10 ± 12.97; 46.83 ± 11.93, respectively). This implies that the four-week corrective exercise program, which was prescribed according to the corrective exercise principles created by the National Academy of Sports Medicine (NASM), did not significantly improve the overall functional movement quality of the participants in relation to the CON group (Figure 6).

The results of this study differ from the other previous research that has demonstrated improvement in functional movement quality after the implementation of a short-term (i.e., 2-3 week) corrective exercise protocol. Specifically, Bell, Oates, Clark, & Padua (2013) utilized the components of the NASM Corrective Exercise Continuum, in a similar manner as the current study, and demonstrated statistically significant reductions in medial knee displacement ($F(1,150) = 4.43$, $p = .001$) and dynamic knee valgus ($F(1,150) = 3.40$, $p = .02$) during a two-leg overhead squat. However, this is the only previously published study that has utilized all components of the NASM Corrective Exercise Continuum in the prescribed corrective exercise intervention. Other corrective exercise interventions that have been previously utilized in the literature, and have demonstrated a capability of significantly improving functional movement quality, have predominantly utilized exercises that only require functional and/or dynamic movements and have excluded the targeted restoration of the observed neuromuscular imbalances through inhibition, lengthening, and isolated strengthening (Figure 3).

It should also be noted that although the altered movement patterns of medial knee displacement and/or knee valgus are included in the movement compensation grading criteria for the Overall ME Test score, these are only two of the potential movement compensations that factor into this score. For example, other upper extremity and cervical spine sub-tests also factor into the Overall ME Test score calculation (Appendix D). Therefore, similar to the FMS, future

research should also examine the influence of corrective exercise programming on individual sub-tests of the ME Test as well.

Although there was not a statistically significant difference in Overall ME Test scores between the CEP group and the CON group after the intervention (i.e., Week 5), it is important to note that the changes in Overall ME Test scores across the intervention among CON group participants were smaller than the changes in Overall ME Test scores across the intervention among CEP group participants (2.25 vs. 4.40, respectively). Ebersole & Cornell (in press) have recently suggested that the *MDD* of the Overall ME Test score is 6.74. While the Overall ME Test scores among participants in the CEP group did not achieve this magnitude of change in the current study, this previously determined *MDD* value was calculated by examining inter-rater reliability data and not intra-rater reliability. Therefore, the Overall ME Test score *MDD* that is associated with intra-rater reliability data remains unknown. Since all ME Tests were conducted and graded by the same researcher in the current study, it is possible that a 4.40 change in Overall ME Test score may in fact be a clinically and practically relevant change, despite a lack in statistical significance. However, future research examining the intra-rater reliability of the ME Test remains necessary.

Covariates. Similar preliminary exploratory analyses were also conducted in the current study to determine if there were statistically significant correlations between age and Overall ME Test score, as well as BMI and Overall ME Test score. In contrast to the Total FMS score data in the current study, as well as the previous FMS literature (Loudon et al., 2014; Perry & Koehle, 2013; Teyhen et al., 2014b), the correlation between age and Overall ME Test was not statistically significant ($r = -.177$, $p = .231$). Therefore, the continuous variable of age (years) was not utilized as a covariate in the RM ANOVAs. However, the non-statistically significant

exploratory correlation identified between BMI and Overall ME Test score ($r = -.195$, $p = .170$) was similar to the non-statistically significant exploratory correlation identified between BMI and Total FMS score ($r = -.159$, $p = .265$). As such, BMI was not utilized as a covariate in the RM ANOVAs. These lack of statistically significant correlations suggest that age and obesity-level may influence the functional movement parameters assessed by the ME Test in a different fashion than that of the FMS. For example, it is possible that obesity-level may impair the functional movement patterns involved in particular sub-tests of the FMS and ME Test differently. Accordingly, future research should also compare and contrast how functional movement quality assessed by the FMS and ME Test is influenced by various anthropometric factors, measures of body composition, and aerobic fitness among the active-duty firefighter population.

Exploratory Analysis #1. It is possible that the lack of supervision or familiarity with the corrective exercise protocol influenced the outcomes. In the strength training literature, previous research suggests that direct supervision by a qualified practitioner (e.g., strength and conditioning coach, personal trainer) during each session of a training program results in greater improvements in muscular strength and power compared to non-supervision (Coutts, Murphy, & Dascombe, 2004; Mazzetti et al., 2000). In the clinical literature, previous research has demonstrated that functional performance, as measured by the one-leg hop test (Reiman & Manske, 2009), is restored over a three year period among patients who completed supervised neuromuscular training and is not restored among patients who completed unsupervised self-monitored neuromuscular training during their anterior cruciate ligament (ACL) rupture rehabilitation protocols (Ageberg, Zätterström, Moritz, & Fridén, 2001). In addition, a recent meta-analysis by Myer, Sugimoto, Thomas, and Hewett (2013) suggests that instruction and

supervision by qualified practitioners and/or clinicians is integral in enhancing the outcomes of various ACL injury prevention programs. These authors speculated that feedback and instruction provided by these qualified individuals may explain the conflicting results in the ACL injury prevention literature regarding the utilization of training programs to prevent such injuries.

Comparable results have also been recently identified among the tactical athlete population, as the risk of lower extremity injury among military cadets was significantly lowered by 41% among participants who completed injury prevention programming that was supervised by licensed clinicians (athletic trainers and/or physical therapists) than among participants who completed injury prevention programming that was supervised by cadet instructors (Carow et al., in press). Similarly, conflicting results regarding the utilization of various training programs to improve lower extremity biomechanics during other functional movement patterns (e.g., drop landings, dynamic balance, etc.) exist in the literature, with some studies demonstrating improvements in lower extremity biomechanics and some studies demonstrating no change in lower extremity biomechanics (Padua & DiStefano, 2009). Thus, it is possible that instruction and feedback provided during supervision by qualified individuals may influence the results observed in this literature body as well.

Accordingly, the lack of supervision during each corrective exercise programming training session, as well as the lack instruction and feedback by a qualified practitioner regarding exercise technique, may have mitigated the influence of the corrective exercise training programming utilized in the current study. Therefore, additional exploratory analyses among a sub-set of participants (N = 9) who were also practitioners themselves and trained in the concept of corrective exercise were conducted. Descriptive data of these participants can be found in

Table 18. No significant differences (p > .05) were identified between groups among any of these descriptive variables.

Table 18

Exploratory Analysis #1: Participant Descriptive Data

Age (yrs)	Mean	*SD*	Range
Total (N = 9)	33.8	4.0	29 – 41
CON (n = 4)	31.5	3.1	29 – 36
CEP (n = 5)	35.6	3.9	31 – 41
Height (cm)	Mean	*SD*	Range
Total (N = 9)	179.7	5.0	170.2 – 189.0
CON (n = 4)	180.1	0.8	179.3 – 181.0
CEP (n = 5)	179.4	7.0	170.2 – 189.0
Weight (kg)	Mean	*SD*	Range
Total (N = 9)	89.8	8.7	74.3 – 99.5
CON (n = 4)	91.9	8.1	81.1 – 99.5
CEP (n = 5)	88.2	10.0	74.3 – 96.8
BMI (kg/m^2)	Mean	*SD*	Range
Total (N = 9)	27.8	2.4	23.8 – 30.8
CON (n = 4)	28.3	2.4	25.2 – 30.8
CEP (n = 5)	27.4	2.5	23.8 – 30.1

Note: yrs, years; cm, centimeters; kg, kilograms; m^2, meters squared; BMI, body mass index

These nine participants were active-duty firefighters who were either already certified Peer Fitness Trainers (PFTs) through the American Council of Exercise (ACE), or were in the process of being trained to become certified PFTs, in the City of Milwaukee Fire Department (MFD, n = 6) or North Shore Fire Department (NSFD, n = 3). These participants were trained in

the principles of exercise technique and instruction and had previous experience with utilizing the Fusionetics Human Performance System online platform for corrective exercise programming. Accordingly, it was deemed plausible that these participants may have demonstrated different results than the other active-duty firefighters recruited in the current study. As such, the same 2 × 3 RM ANOVAs (Group × Time) were conducted in an exploratory fashion among this sub-set participant population.

Total FMS score results**.** Results of the exploratory analyses among the Total FMS score data suggest the changes in Total FMS scores from pre- to post-intervention were actually greater among the CON group than the CEP group (-1.8 vs. 0.8, respectively), with the Total FMS scores among the CON group participants actually decreasing across time (Figure 8). This suggests that the role of being a PFT did not influence the changes in Total FMS scores across the four-week corrective exercise intervention.

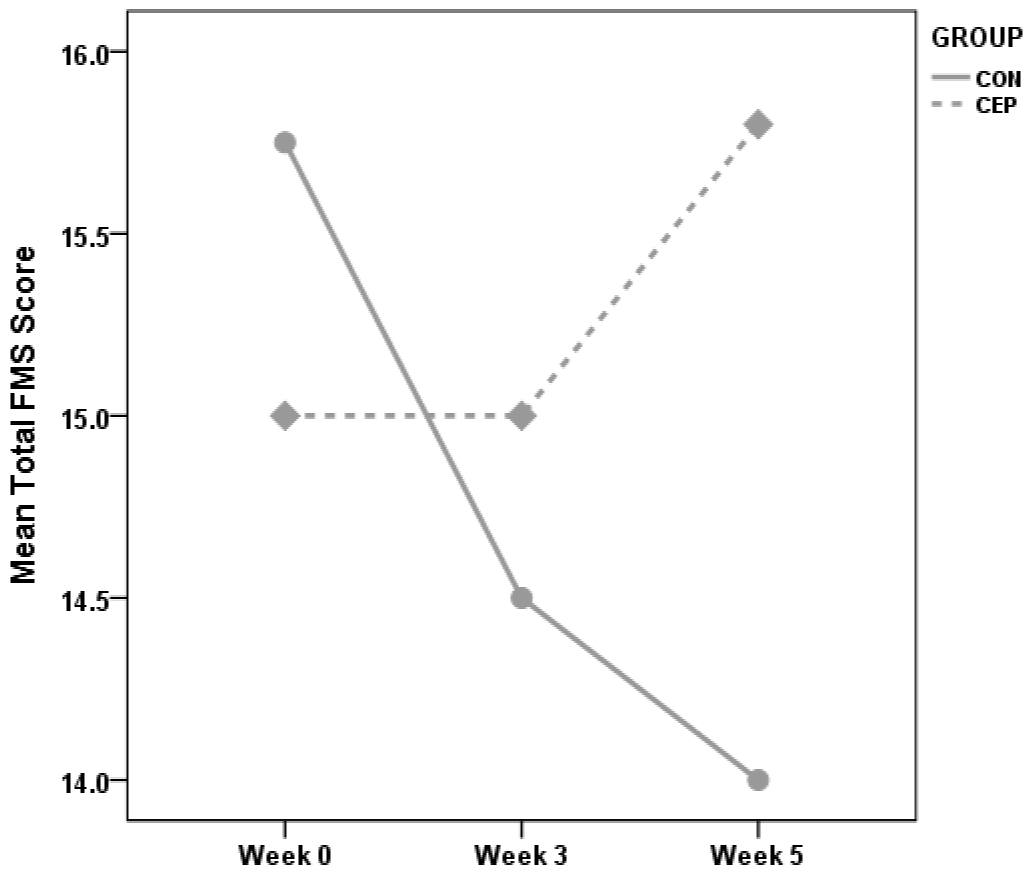

Figure 8. Change in Total FMS scores among PFT participants.

Specifically, although the 2 × 3 within-between RM ANCOVA indicated an interaction effect between the Time and Group factors that was approaching statistical significance ($F(2,12) = 3.518$, $p = .063$) with a large effect size ($\eta^2_p = .370$, $1–\beta = .541$), the follow-up tests of simple effects did not identify a statistically significant difference ($F(1,6) = 0.529$, $p = .495$; $\eta^2_p = .081$) between the CON and CEP groups at Week 5 (14.0 ± 1.6 vs. 15.8 ± 4.4, respectively), nor was there a significant main effect of Time among the CEP group ($F(2,6) = 0.259$, $p = .780$; $\eta^2_p = .079$). However, it should be noted that the decrease in Total FMS scores among the CON group (-1.8) was approaching the point of being considered a *real* change, and thus, practical relevance,

as it was approaching the previously determined intra-rater *MDD* of 1.9 for the primary researcher of this study (Cornell et al., unpublished laboratory data). Thus, although the corrective exercise programming did not improve the Total FMS scores among the CEP group participants, this programming did appear to at least inhibit the potential decrease in functional movement quality over time among these participants.

Overall ME Test score results. However, the results of the exploratory analyses among the Overall ME Test score data suggest that the role of being a PFT may have influenced the changes in Overall ME Test scores across the four-week corrective exercise intervention. Specifically, although the 2 × 3 within-between RM ANOVA indicated that the interaction effect between the Time and Group factors was not statistically significant ($F(2,14) = 0.438$, $p = .654$, $\eta^2_p = .059$), these results demonstrate that the changes in Overall ME Test scores from pre- to post-intervention were greater among the CEP group than the CON group (4.66 vs. -2.04, respectively), with the Overall ME Test scores among the CEP group increasing and Overall ME Test scores among the CON group participants decreasing slightly across time (Figure 9).

In addition, although the main effect of Time among the CEP group was not statistically significant ($F(2,8) = 1.149$, $p = .364$), a large effect size was still observed ($\eta^2_p = .223$) among the CEP group. However, due to such a small sample size in this follow-up exploratory analysis, a lack of statistical power should be noted ($1–\beta = .187$). Finally, although the change in Overall ME Test scores among the CEP group (4.66) did not reach the previously determined inter-rater *MDD* of 6.74, when taking into consideration the decrease in Overall ME Test scores among the CON group (-2.04), this overall combined effect of 6.70 was nearly the point of being considered practically relevant (i.e., 4.66 + 2.04 = 6.70).

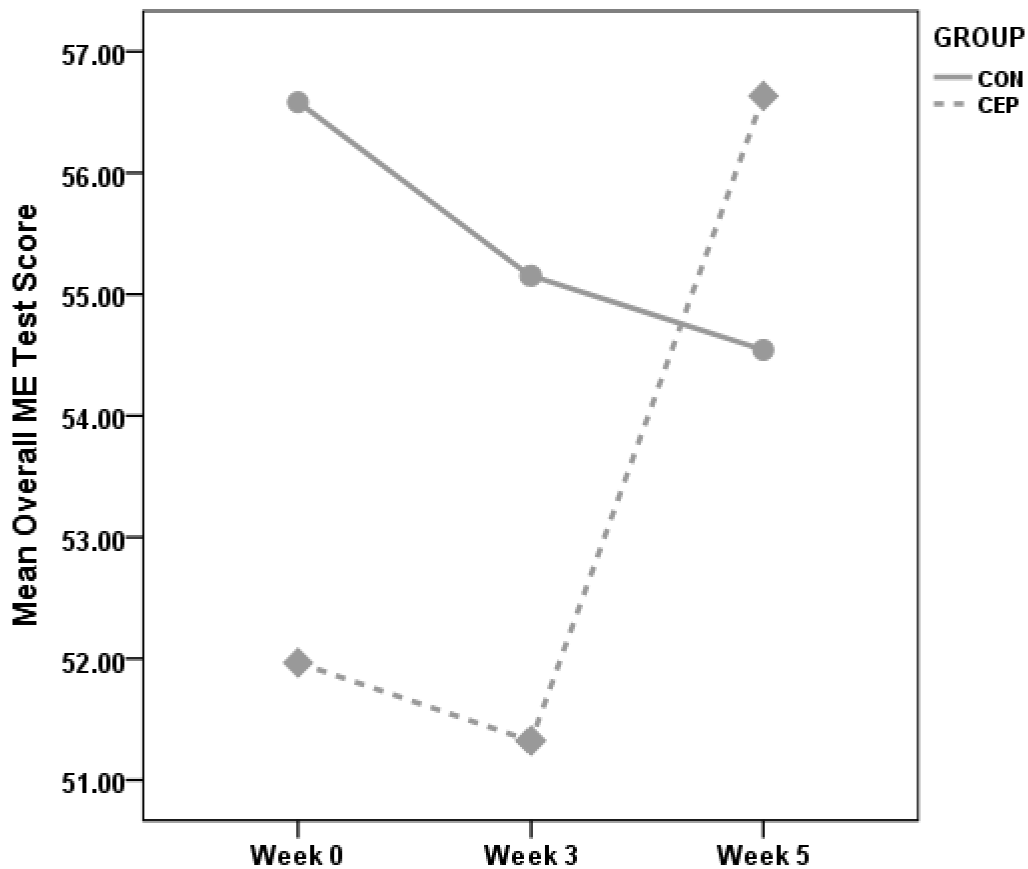

Figure 9. Change in Overall ME Test scores among PFT participants.

Exploratory Analysis #2. It is also possible that participants who demonstrated higher quality of functional movement before the intervention had less room for improvement from a corrective exercise program intervention. In contrast, it is possible that those who demonstrated a lower quality of functional movement before the intervention had more room for improvement from a corrective exercise program intervention. This bifurcation in potential intervention outcomes has been previously demonstrated by other researchers. For example, DiStefano, Padua, DiStefano, and Marshall (2009) identified differences in the improvement of functional movement quality during a jump-landing test, known as the Landing Error Scoring System

(LESS), based upon the participant's pre-intervention quality of functional movement. Specifically, participants with a poorer quality of functional movement (i.e., higher LESS scores) improved to a greater extent than participants with a better quality of functional movement. Therefore, it is possible that similar outcomes could be identified in the current study as well.

Accordingly, additional exploratory analyses among a sub-set of 24 participants (MFD = 18, NSFD = 6) who demonstrated *poor* functional movement quality were conducted. Specifically, potential changes in functional movement quality were examined among all participants who demonstrated a Week 0 Overall ME Test score that was below the mean score of the entire sample population (44.42). As such, the same 2 × 3 RM ANOVAs (Group × Time) were conducted in an exploratory fashion among this sub-set participant population. Descriptive data of these participants can be found in Table 19. No significant differences ($p > .05$) were identified between CON ($n = 11$) and CEP ($n = 13$) groups among any of these descriptive variables.

Table 19

Exploratory Analysis #2: Participant Descriptive Data

Age (yrs)	Mean	*SD*	Range
Total (*N* = 24)	41.5	7.4	28 – 55
CON (*n* = 11)	39.7	8.0	29 – 55
CEP (*n* = 13)	43.1	6.7	28 – 52
Height (cm)	Mean	*SD*	Range
Total (*N* = 24)	181.4	5.9	171.0 – 191.0
CON (*n* = 11)	181.6	5.8	179.3 – 181.0
CEP (*n* = 13)	181.2	6.2	171.0 – 191.0
Weight (kg)	Mean	*SD*	Range
Total (*N* = 24)	92.6	7.4	77.7 – 104.1
CON (*n* = 11)	94.1	7.2	78.4 – 104.1
CEP (*n* = 13)	91.4	7.7	77.7 – 104.1
BMI (kg/m^2)	Mean	*SD*	Range
Total (*N* = 24)	28.2	2.7	25.1 – 35.6
CON (*n* = 11)	28.6	2.6	25.8 – 35.3
CEP (*n* = 13)	27.9	2.8	25.1 – 35.6

Total FMS score results. Independent samples *t* tests indicated no statistically significant differences in Total FMS scores between MFD and NSFD participants ($t(22) = -0.496$, $p = .625$; $t(22) = -0.211$, $p = .835$; $t(22) = -0.387$, $p = .702$, respectively) at Week 0, Week 3, or Week 5 (10.9 ± 2.3 vs. 11.5 ± 2.5; 12.2 ± 1.7 vs. 12.3 ± 1.6; 12.5 ± 1.7 vs. 12.8 ± 2.1, respectively). In addition, the Mauchly's Test of Sphericity confirmed the assumption of sphericity in the data (Mauchly's $W(2) = 0.806$, $p = .115$).

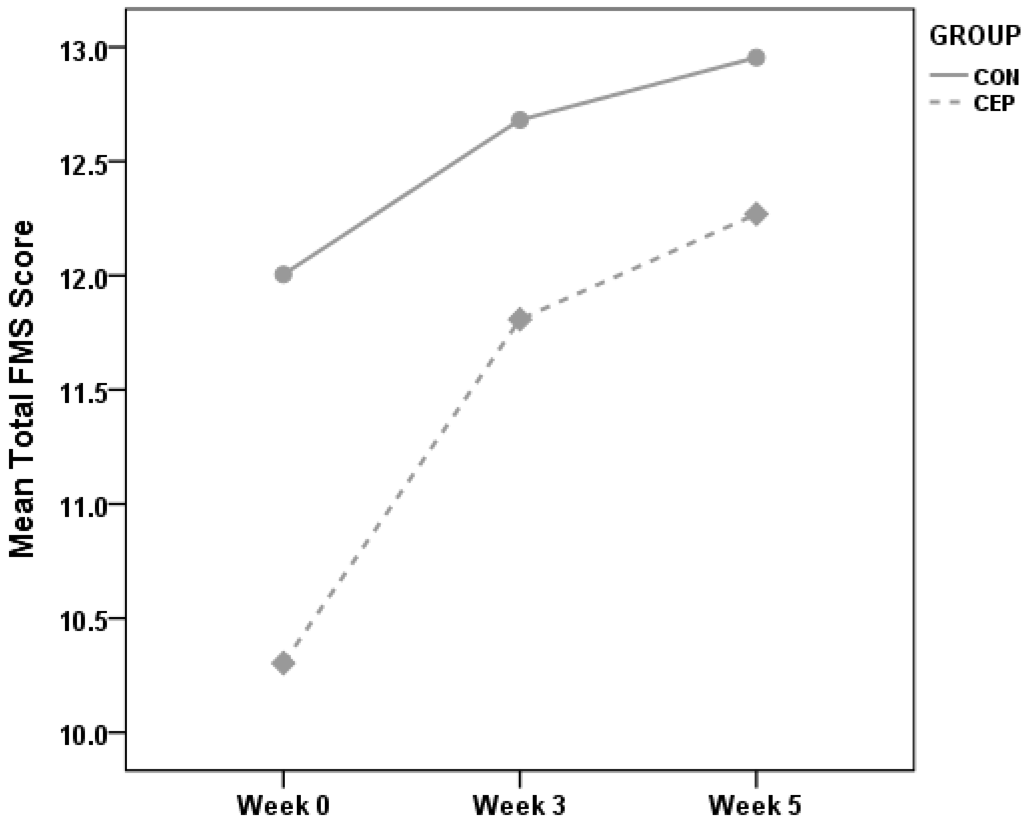

Figure 10. Change in Total FMS scores among participants with poor functional movement quality.

Results of the 2 × 3 within-between RM ANCOVA, with the continuous variable of age as a covariate, failed to identify a statistically significant interaction effect between the Time and Group factors ($F(2,42) = 1.337$, $p = .274$, $\eta^2_p = .060$). In addition, a statistically significant main effect of Time was not identified ($F(2,42) = 1.660$, $p = .202$, $\eta^2_p = .073$). Furthermore, when split by groups, a statistically significant main effect of Time was not identified in either the CON or the CEP groups as well ($F(2,18) = 2.857$, $p = .084$, $\eta^2_p = .241$; $F(2,22) = 0.708$, $p = .503$, $\eta^2_p = .060$, respectively). These results suggest that were no statistically significant differences

in Total FMS scores between the CON and CEP groups, as well as within each group, pre, mid, or post (12.3 ± 2.2 vs. 10.1 ± 2.0; 12.8 ± 1.9 vs. 11.7 ± 1.2; 13.1 ± 1.6 vs. 12.2 ± 1.9, respectively) the four-week corrective exercise intervention (Figure 10).

Overall ME Test score results. Independent samples *t* tests indicated no statistically significant differences in Total FMS scores between MFD and NSFD participants ($t(22) = 0.093$, $p = .927$; $t(22) = -1.570$, $p = .131$; $t(22) = -0.515$, $p = .612$, respectively) at Week 0, Week 3, or Week 5 (34.61 ± 5.79 vs. 34.34 ± 7.87; 40.12 ± 8.99 vs. 48.10 ± 15.39; 40.42 ± 9.32 vs. 42.83 ± 11.73, respectively). In addition, the Mauchly's Test of Sphericity confirmed the assumption of sphericity in the data (Mauchly's $W(2) = 0.705$, $p = .705$).

Similar to the Total FMS score, the results of the 2 × 3 within-between RM ANOVA among the Overall ME Test score data failed to identify a statistically significant interaction effect between the Time and Group factors ($F(2,44) = 2.450$, $p = .098$, $\eta^2_p = .100$). However, a statistically significant and large main effect of Time was in fact identified ($F(2,44) = 10.002$, $p < .001$, $\eta^2_p = .313$). Specifically, follow-up pairwise analyses indicated that the Overall ME Test scores significantly ($p < .05$) increased from Week 0 to Week 3 (34.54 ± 6.19 vs. 42.12 ± 11.12, respectively) and that the Overall ME Test scores at Week 5 remained significantly higher than the Week 0 scores (41.02 ± 9.76 vs. 34.54 ± 6.19, respectively). However, there was not a statistically significant difference ($p < .05$) between Overall ME Test scores at Week 3 and Week 5 (42.12 ± 11.12 vs. 41.02 ± 9.76, respectively). These results suggest that irrespective of group membership, Overall ME Test scores significantly increased from pre- to mid-intervention and that this improvement in functional movement quality, as determined by the ME Test, was maintained in Week 5 (Figure 11).

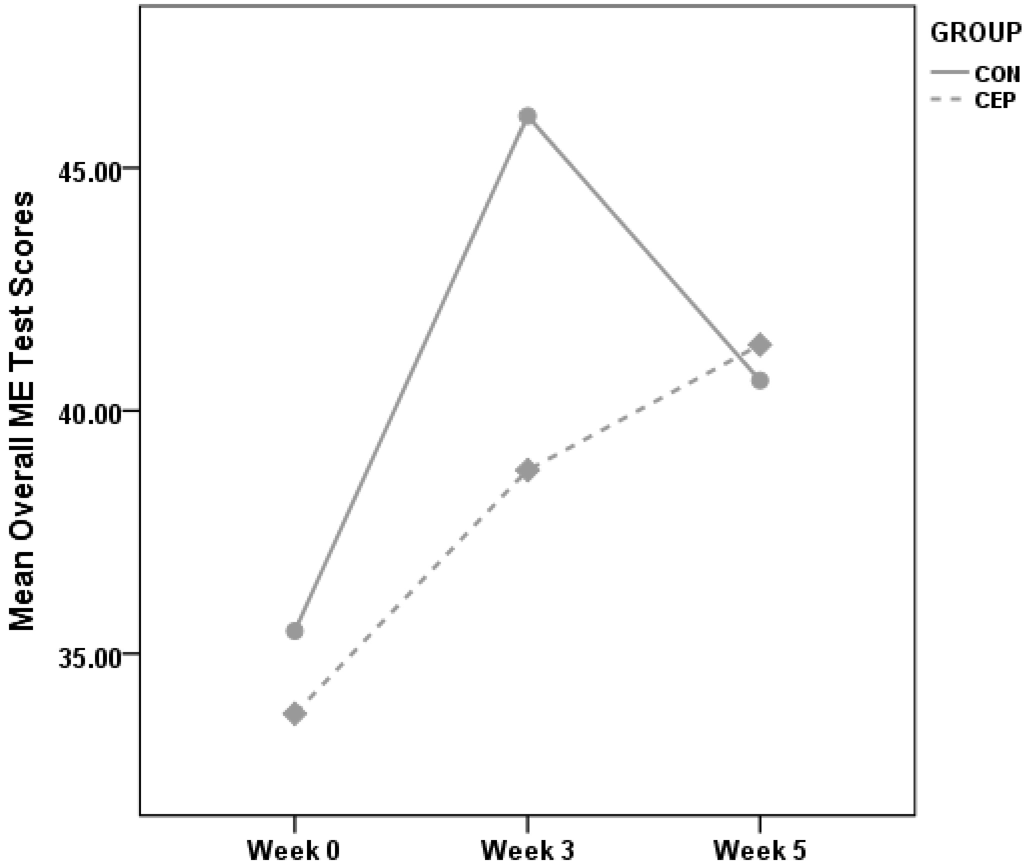

Figure 11. Change in Overall ME Test scores among participants with poor functional movement quality.

Furthermore, additional exploratory analyses were also conducted when split by groups. These analyses identified a statistically significant and large main effect of Time in both of the CON and the CEP groups as well ($F(2,20) = 8.883$, $p = .002$, $\eta^2_p = .470$; $F(2,24) = 4.173$, $p = .028$, $\eta^2_p = .258$, respectively). Specifically, follow-up pairwise analyses indicated that the Overall ME Test scores significantly ($p < .05$) increased from Week 0 to Week 3 among the CON group (35.47 ± 5.49 vs. 46.07 ± 11.03, respectively) and that the Overall ME Test scores significantly ($p < .05$) increased from Week 0 to Week 5 among the CEP group (33.76 ± 6.84 vs.

41.36 ± 9.29, respectively). All other pairwise analyses were not statistically significant (p > .05).

Collectively, these results suggest that although there were no statistically significant differences in Overall ME Test scores between CON and CEP groups, and that both groups significantly improved their Overall ME Test scores from Week 0 to Week 3, the participants in the CEP group appeared to incrementally improve their Overall ME Test scores throughout the entire intervention, while the Overall ME Test scores among the participants in the CON group began to regress back to the original Week 0 values. Furthermore, the change in Overall ME Test scores from pre- to post-intervention among the CEP group participants (7.60) exceeded the previously described *MDD* of 6.70 (Ebersole & Cornell, in press). However, it should also be noted the change in Overall ME Test scores from pre- to mid-intervention in the CON group (10.6) also exceeded this *MDD* as well. As such, results of these exploratory analyses should be taken with caution. Nevertheless, when combined with the results of DiStefano et al. (2009), future research should examine the potential influence of initial functional movement quality on the outcomes of similar corrective exercise programming interventions.

Summary. In summary, the results associated with the primary aim of the current study suggest that the four-week corrective exercise programming created by the Fusionetics Human Performance System did not elicit significant improvements in functional movement quality among active-duty firefighters. As such, a short-term unsupervised corrective exercise program did not significantly decrease the theoretical risk of future MSKI in this cohort population. Based on these results, it is possible that a four-week corrective exercise program, as suggested by the NASM Corrective Exercise Continuum, is not a long enough intervention to elicit significant changes in functional movement quality among this cohort population. In addition,

although the corrective exercises themselves were individualized to the functional movement compensations demonstrated by each participant, it is also possible that individualizing the progression of these corrective exercises across the four-week intervention (Table 3) could influence the efficacy of the corrective exercise programming as well. For example, it is possible some participants needed a more rapid progression of this programming, and others needed a slower progression of this programming, in order to elicit significant changes in functional movement quality in the four-week timeframe.

However, some meaningful trends in Total FMS score and Overall ME Test score improvements were identified among the nine PFT participants, suggesting that previous experience utilizing the Fusionetics Human Performance System online platform and familiarization with the associated exercises prescribed in the corrective exercise programming may have influenced the results of the current study. In addition, when combined with the influence of instruction and feedback on training intervention outcomes previously identified in various bodies of literature, these results suggest that instruction and feedback provided during training sessions, supervised by qualified individuals, may influence the efficacy of the corrective exercise programming utilized in the current study. As such, future research should examine the potential influence of supervised and non-supervised corrective exercise training programming on changes in functional movement quality among active-duty firefighters. Furthermore, the results of the current study also suggest that future research should examine the potential influence of initial functional movement quality on the outcomes of such corrective exercise programming interventions among active-duty firefighters as well.

Finally, since other movement assessments are becoming prominent in both the traditional athlete (Dallinga, Benjaminse, & Lemmink, 2012) and tactical athlete literature bodies

(Teyhen et al., 2014a), future research should also examine the potential influence of various corrective exercise training programming on these other movement assessments. These assessments may include, but are not limited to, the Star Excursion Balance Test (SEBT) and/or the Y-Balance Test (YBT) (Gribble, Hertel, & Plisky, 2012), the Balance Error Scoring System (BESS) (Bell, Guskiewicz, Clark, & Padua, 2011), and the LESS (Padua et al., 2015). Since all of these movement assessments have become commonly utilized by both practitioners and researchers to assess injury risk among various athlete populations, it is possible that corrective exercise programming may influence the outcomes on one of these movement assessments more than the others.

Specific Aim #2

Introduction. The secondary aim of the current study was to examine the influence of a four-week corrective exercise intervention on various health and fitness measures that have been previously associated with functional movement quality among the firefighter population. These health and fitness measures included total body power output, lower extremity muscular strength, and core muscular endurance, which are measures included in The Fire Service Joint Labor Management Wellness-Fitness Initiative (WFI) created by the International Association of Fire Fighters (IAFF) and the International Association of Fire Chiefs (IAFC). These measures of health and fitness were specifically quantified as maximal countermovement jump (CMJ) height (cm), one-repetition maximal isometric deadlift ($1RM_{Deadlift}$) strength normalized to bodyweight (kg/kg), and prone plank ($Plank_{max}$) time in seconds (sec), respectively. It was hypothesized that a four-week corrective exercise program intervention would significantly improve these various measures of health and fitness among active-duty firefighters.

Total body power output. Previous research has identified a significant direct relationship between Total FMS score and CMJ height among firefighter recruits (Cornell et al., unpublished laboratory data). As such, it was hypothesized that a corrective exercise program intervention may be capable of increasing the total body power output of male active-duty firefighters. However, in contrast to this hypothesis, no significant differences in CMJ height were identified between the CON and CEP groups at Week 5 in the current study (Table 9). In fact, when collapsed across groups, a statistically significant decrease in CMJ height among these participants was observed over the four-week intervention period ($F(1,41) = 325.074$, $p < .001$) and large main effect of Time ($\eta^2_p = .888$) was identified. This suggests that irrespective of group membership, the total body power output of the active-duty firefighters actually decreased pre to post the four-week corrective exercise intervention (44.9 ± 8.6 cm vs. 38.7 ± 7.7 cm, respectively).

However, it should be noted that the functional movement quality among the participants in the current study did not significantly increase as a result of the corrective exercise program intervention as well. In addition, exploratory bivariate Pearson correlations during the pre-intervention phase (i.e., Week 0) suggest that there is in fact a significant direct relationship between CMJ height and Total FMS score ($r = .527$, $p < .001$), as well as between CMJ height and Overall ME Test score ($r = .441$, $p = .002$). In fact, both of these correlations are larger than the correlation previously observed by Cornell et al. (unpublished laboratory data) among firefighter recruits ($r = .392$, $p = .026$), suggesting that CMJ height among active-duty firefighters may be even more susceptible to change with concurrent increases in functional movement quality than their recruit counterparts. It is possible that since the corrective exercise programming utilized in the current study did not yield a significant improvement in functional

movement quality, a lack of improvement in CMJ height is not surprising. Furthermore, previous research has also demonstrated in significant increases in CMJ height following a neuromuscular injury prevention program among other athlete populations (DiStefano, Padua, Blackburn, Garrett, Guskiewicz, & Marshall, 2010). Although CMJ height is considered a standard field test of total body power output (McGuigan, 2016), it is possible that different results may be identified by utilizing more direct assessment of power output (e.g., force plate with three-dimensional motion capture capabilities). As such, future research should investigate potential improvements in CMJ height and/or total body power output when utilizing other variations in corrective exercise programming among the active-duty firefighter population.

Lower extremity muscular strength. Previous research by Cornell, Gnacinski, Zamzow, Mims, and Ebersole (in press[a]) identified a significant direct relationship between Total FMS score and barbell squat one-repetition maximal strength among male firefighter recruits (r = .302, p = .007). As such, it was hypothesized that a corrective exercise program intervention aimed at improving functional movement quality may be capable of increasing the lower extremity strength of male active-duty firefighters. In contrast to this hypothesis, no statistically significant differences in one-repetition maximal isometric deadlift ($1RM_{Deadlift}$) strength were identified between the CON and CEP groups at Week 5 in the current study (Table 9). In addition, when examining the $1RM_{Deadlift}$ data among just the participants in the CEP group, no statistically significant changes from pre- to post-intervention were identified as well (1.46 ± 0.38 kg/kg vs. 1.47 ± 0.34 kg/kg, respectively).

It should be noted, however, that this previous research utilized a barbell squat exercise during one-repetition maximal strength testing protocol (Cornell et al., in press[b]), which is a isotonic exercise movement. In contrast, the $1RM_{Deadlift}$ maximal muscular strength assessment

utilized in the current study was an isometric (i.e., no change in joint angle) assessment of maximal lower extremity muscular strength, and thus, no actual functional movement was involved in the muscular strength assessment. Therefore, the lack of a functional movement pattern involved in the actual muscular strength assessment may have influenced outcomes of the current study in comparison to the previous literature. As such, it is possible that since a different assessment of maximal lower extremity muscular strength was utilized, any potential influence of the corrective exercise programming on the expression of muscular strength may have gone undetected in the current study.

Further exploratory bivariate Pearson correlations conducted during the pre-intervention phase (i.e., Week 0) in the current study suggest that that relationships between functional movement quality and maximal muscular strength may differ based on which functional movement assessment is being utilized. For example, as the correlation between $1RM_{Deadlift}$ and Total FMS score was statistically significant (r = .485, p < .001), but the correlation between $1RM_{Deadlift}$ and Overall ME Test score was not (r = .162, p = .281). Accordingly, since the corrective exercise programming utilized in the current study was developed based on the movement patterns displayed during each participant's ME Test, it is possible that the corrective exercise programming created by the Fusionetics Human Performance System does not influence the expression of muscular strength in the same manner as other corrective exercise programs. Thus, future research should examine the influence of other corrective exercise programming on the expression of maximal muscular strength among active-duty firefighters.

Core muscular endurance. Previous research by Cornell et al. (in press[a]) also identified a significant direct relationship between Total FMS score and prone plank ($Plank_{max}$) time among male firefighter recruits (r = .320, p = .004). As such, it was hypothesized that a

corrective exercise program intervention aimed at improving functional movement quality may be capable of increasing the core muscular endurance of male active-duty firefighters. In contrast to this hypothesis, no statistically significant differences in $Plank_{max}$ were identified between the CON and CEP groups in the current study (Table 14).

However, a statistically significant ($F(1,42) = 11.618$, $p = .001$) and large main effect of Time ($\eta^2_p = .217$) was identified when collapsed across all participants. This implies that irrespective of group members, the $Plank_{max}$ time significantly increased from pre- to post-intervention (146.8 ± 59.2 sec vs. 171.2 ± 64.4 sec, respectively). These results suggest that familiarization to the prone plank test itself may result in a significantly improved $Plank_{max}$ time, regardless of a corrective exercise program intervention. These results differ from research in the previous literature that suggests that the prone plank test is considered a valid and reliable assessment of core muscular endurance with excellent test-retest reliability ($r = .78$, $p < .05$) among men and women (Schellenberg, Lang, Chan, & Burnham, 2007). Therefore, it is possible that the test-retest reliability of this prone plank test differs among male active-duty firefighters and future research should determine the actual test-retest reliability, as well as the potential learning effect associated with this measure, within this cohort population.

Furthermore, exploratory bivariate Pearson correlations conducted during the pre-intervention phase (i.e., Week 0) in the current study suggest that that relationships between functional movement quality and core muscular endurance may differ based on which functional movement assessment is being utilized as the correlation between $Plank_{max}$ and Total FMS score was statistically significant ($r = .297$, $p = .038$), but the correlation between $Plank_{max}$ and Overall ME Test score was not ($r = .257$, $p = .075$). Since the corrective exercise programming utilized in the current study was developed based on the movement patterns displayed during each

participant's ME Test, it is possible that the corrective exercise programming created by the Fusionetics Human Performance System does not influence the core muscular endurance ability in the same manner as other corrective exercise programs. Thus, future research should examine the influence of other corrective exercise programming on core muscular endurance among active-duty firefighters.

Summary. In summary, the results associated with the secondary aim of the current study suggest that the four-week corrective exercise programming created by the Fusionetics Human Performance System did not elicit significant improvements in the health and fitness measures of total body power output, lower extremity muscular strength, and core muscular endurance among active-duty firefighters. It is possible that since the corrective exercise programming did not elicit significant improvements in functional movement quality, there were not a concomitant increase in these measures of health and fitness. It is also possible that the change in functional movement quality needed to create a subsequent change in measures of health and fitness is larger than a clinically relevant change in functional movement, or that the timeline of these health and fitness adaptations does not concurrently match the timeline of changes in functional movement quality. As such, when coupled with the fact that the corrective exercise programming did not yield statistically significant improvements in functional movement quality, future research should examine the potential influence of supervised and non-supervised corrective exercise training programming that is aimed at improving functional movement quality on measures of health and fitness among active-duty firefighters.

Specific Aim #3

Introduction. Although the utilization of various functional movement screening tools has grown among practitioners, the FMS is currently the only method of quantifying functional

movement quality that has been utilized in the literature among researchers. Since the utilization of other assessments of functional movement quality are becoming more common within the firefighter population, such as the ME Test associated with the Fusionetics Human Performance System, the examination of the criterion-reference validity of this functional movement assessment to the already established FMS is warranted.

Therefore, the tertiary aim of the current study utilized the functional movement data collected during the pre-intervention phase (i.e., Week 0) to investigate the criterion-reference validity of the Overall ME Test score in reference to the Total FMS score among this sample population of male active-duty firefighters. It was hypothesized that a good-to-excellent positive correlation (r = .76 – 1.00), as described by Portney and Watkins (2009), would be identified. This would imply that the ME Test has a strong relationship with the already established FMS, and thus, would establish the criterion-reference validity of this relatively new assessment of functional movement quality among the active-duty firefighter population.

Criterion-reference validity. Results of the bivariate Pearson correlation analysis conducted in the current study identified a statistically significant and direct correlation between Total FMS and Overall ME Test scores (r = .634, p < .001, $1–\beta$ > .999, 95% CI = 0.430 – 0.776). Although the results of this correlation suggest that a moderate-to-good relationship (Portney & Watkins, 2009) between Total FMS and Overall ME Test scores (Figure 7), this correlation coefficient is less than the originally hypothesized correlation (r = .634 vs. r = .76 – 1.00, respectively). Additionally, these results also suggest that the Overall ME Test score only explains roughly 40.3% of the variance of the Total FMS score (R^2 = .403). It has been suggested that in order for a new assessment to hold a high level of criterion-reference validity, this new assessment should demonstrate good-to-excellent positive correlation with the already

established assessment (Jewell, 2015). Based on this criteria, the newly developed ME Test may lack criterion-reference validity in relation to the FMS among the population of active-duty firefighters.

When coupled with the differing exploratory correlations between obesity-level and age and these functional movement assessments previously described in Specific Aim #1, it is possible that the FMS and ME Test do not quantify functional movement quality in the same manner. Specifically, age was significantly correlated to Total FMS score, but not Overall ME Test score, and obesity-level was not significantly correlated to either movement assessments. Based on these findings, it is possible that various anthropometric factors (e.g., age, height, etc.) or body composition factors (e.g., body fat percentage, fat free mass, etc.) may influence these assessments differently. If so, other external factors (i.e., outside of the assessment itself) may alter the validity of a given test. For example, Cornell, Gnacinski, Zamzow, Mims, and Ebersole (in press[b]) also identified a significant correlation between fat-free mass (FFM) and Total FMS score among firefighter recruits (r = -0.231, p = 0.049). It is possible that such factors influence the FMS and ME Test to differing degrees, resulting in a decline of criterion-reference validity between the two measures.

In addition, the exploratory correlations conducted in Specific Aim #2 between various measures of health and fitness and functional movement also differed between the two functional movement assessments. For example, the correlations between Total FMS score and $1RM_{Deadlift}$ and $Plank_{max}$ were both statistically significant (r = .485, p < .001; r = .297, p = .038, respectively), but the correlations between Overall ME Test score and $1RM_{Deadlift}$ and $Plank_{max}$ were not statistically significant (r = .162, p = .281; r = .257, p = .075, respectively). Therefore,

although there is a significant relationship between Total FMS and Overall ME Test scores, there appear to be differing contributing factors influencing these assessments.

Finally, due to population sample restrictions among female participants (*n* = 2), the current study only utilized male active-duty firefighters in the statistical analyses. However, previous research suggests that the quality of functional movement patterns associated with the FMS may differ between sexes (Agresta, Slobodinsky, & Tucker, 2014; Anderson, Neumann, & Huxel Bliven, 2015; Gnacinski, Cornell, Meyer, Arvinen-Barrow, & Earl-Boehm, in press; Knapik, Cosio-Lima, Reynolds, & Shumway, 2015; Letafatkar, Hadadnezhad, Shojaedin, & Mohamadi, 2014; Loudon, Parkerson-Mitchell, Hildebrand, & Teague, 2014). As such, researchers (Gnacinski et al., in press) and practitioners (Ransdell & Murray, 2016) alike have questioned the validity of FMS grading across sexes among traditional athlete populations, but it remains unknown if similar discrepancies exist between sexes among the active-duty firefighter population, as well as within the ME Test in general. When coupled with the differing exploratory correlations conducted between the ME Test and other measures of interest, if the ME Test is not in fact influenced by sex among the active-duty firefighter population, it is possible that this assessment may be more appropriate for this population sample as it seems to be influenced less by other external factors. Accordingly, future research should examine the influence of various anthropometric, body composition, and health and fitness, as well as the potential influence of age and sex, on both the FMS and ME Test among the active-duty firefighter population.

Summary. In summary, even though a statistically significant and direct relationship exists between these two assessments of functional movement quality, the ME Test may lack criterion-reference validity in relation to the FMS among this sample population of active-duty

firefighters. Accordingly, it is possible that the ME Test may fundamentally measure functional movement quality differently than the FMS among this cohort population.

Chapter VI: Conclusions

Introduction

The occupation of firefighting is considered to be one of the most dangerous occupations in the United States (Kurlick, 2009), as firefighters are 3.8 times more likely to suffer a work-related musculoskeletal injury (MSKI) than a private-sector worker (Seabury & McLaren, 2010), creating an extremely large financial impact on fire departments across the United States (U.S.) with an estimated total annual cost attributed to injuries among firefighters between $2.8 to $7.8 billion per year (TriData Corporation, 2005). Previous research suggests that functional movement quality may be related to MSKI risk among traditional athlete populations (Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010; Garrison, Westrick, Johnson, & Benenson, 2015; Hotta et al., 2015; Kiesel, Butler, & Plisky, 2014; Kiesel, Plisky, & Voight, 2007; Mokha, Sprague, & Gatens, in press), as well as tactical athlete populations (Knapik, Cosio-Lima, Reynolds, & Shumway, 2015; Lisman, O'Connor, Deuster, & Knapik, 2013; O'Connor, Deuster, Davis, Pappas, & Knapik, 2011), including firefighters (Butler, Contreras, Burton, Plisky, Goode, & Kiesel, 2013; Peate, Bates, Lunda, Francis, & Bellamy, 2007). In addition, recent research suggests that various health and fitness measures are associated with functional movement quality among the firefighter population (Cornell, Gnacinski, Zamzow, Mims, & Ebersole, in press[a]; Cornell, Gnacinski, Zamzow, Mims, & Ebersole, in press[b], Cornell et al., unpublished laboratory data). Therefore, if a corrective exercise program was capable of eliciting improvements in functional movement quality among active-duty firefighters, it may be possible to concomitantly improve health and fitness, as well as decrease MSKI risk, among this cohort population of tactical athletes.

Specific Aims

Accordingly, active-duty firefighters were recruited to participate in the pre-intervention (Phase 1) and intervention (Phase 2) portions of the current study. Phase 1 of the current study examined the relationship between two different functional movement assessments among the active-duty firefighter population: the Functional Movement Screen (FMS) and the Movement Efficiency (ME) Test associated with the Fusionetics Human Performance System. Phase 2 of the current study examined the influence of a four-week corrective exercise program intervention on measures of functional movement, as well as measures of health and fitness, among active-duty firefighters through the use of a quasi-experimental design. Functional movement quality was quantified as Total FMS and Overall ME Test scores, respectively. Participants were placed into either the Corrective Exercise Program (CEP) group or the Control (CON) group in a counterbalanced fashion, based on their respective Overall ME Test score.

Specific Aim #1. The primary aim of the current study was to examine the influence of a four-week corrective exercise program intervention on measures of functional movement among active-duty firefighters. Based on the results of the current study, the four-week corrective exercise programming created by the Fusionetics Human Performance System did not elicit significant improvements in functional movement quality among active-duty firefighters. As such, a short-term corrective exercise program did not significantly decrease the theoretical risk of future MSKI in this cohort population.

However, exploratory analyses suggest that participants who hold a level of previous experience utilizing the Fusionetics Human Performance System online platform, as well as familiarization with the associated exercises prescribed in the corrective exercise programming itself, may influence the changes in functional movement quality as meaningful trends in Total

FMS score and Overall ME Test score improvements were identified among these participants. These results suggest that supervision by qualified individuals during training sessions may influence the efficacy of the corrective exercise programming utilized in the current study.

Specific Aim #2. The secondary aim of the current study was to examine the influence of a four-week corrective exercise intervention on various health and fitness measures that have been previously associated with functional movement quality among the firefighter population. These health and fitness measures included total body power output, lower extremity muscular strength, and core muscular endurance. Based on the results of the current study, the four-week corrective exercise programming created by the Fusionetics Human Performance System did not elicit significant improvements in these various measures of health and fitness. However, it is plausible that since the corrective exercise programming did not elicit significant improvements in functional movement quality, there were not a concomitant increase in these measures of health and fitness. It is also possible that the change in functional movement quality needed to create a subsequent change in measures of health and fitness is larger than a clinically relevant change in functional movement, or that the timeline of these health and fitness adaptations does not concurrently match the timeline of changes in functional movement quality.

Specific Aim #3. The tertiary aim of the current study utilized the functional movement data collected during the pre-intervention phase (Phase 1) to investigate the criterion-reference validity of the Overall ME Test score in reference to the Total FMS score among this sample population of male active-duty firefighters. Results of the current study suggest that even though a statistically significant and direct relationship was identified between these two assessments of functional movement quality, the ME Test may lack criterion-reference validity in relation to the FMS among this sample population of active-duty firefighters. Accordingly, it is possible that

the ME Test may fundamentally measure functional movement quality differently than the FMS among this cohort population. Specifically, various anthropometric, body composition, and health and fitness variables, as well as potentially age and sex, may influence the FMS and ME Tests differently resulting in a decline of criterion-reference validity between the two measures.

Limitations

The most noteworthy limitation of the current study was the method in which compliance was monitored and assessed. Although data regarding intervention compliance were collected, and only one non-compliant participant was removed from the associated statistical analyses, these compliance data were self-reported in nature. Thus, reporting error by the participants could have influenced the outcomes of the current study. This is an important consideration as compliance to the training program is an important factor in corrective exercise and injury prevention training outcomes. For example, recent meta-analysis of various anterior cruciate ligament (ACL) neuromuscular training injury prevention programs (Sugimoto et al., 2012) suggests that females athletes who demonstrated low compliance rates (< 33.3%) to the training programs held a relative ACL injury risk that was 4.9 times greater (incident rate ration = 0.88 vs. 0.18) than females athletes who demonstrated high compliance rates (> 66.6%). Furthermore, previous research suggests that supervision of a resistance training program results in a significantly greater compliance rate among athletes (Coutts, Murphy, & Dascombe, 2004). As such, the previously discussed limitations regarding training supervision, as well as compliance with the training program, should be considered mitigating factors in the influence of the corrective exercise programming utilized in the current study on changes in functional movement quality and health and fitness outcomes.

Another potential limitation of the current study was the influence of the occupation of firefighting itself on measures of functional movement and health and fitness. Although no significant decreases in functional movement quality were identified in the CON group of this study, a trend for decreases were noted in the exploratory analyses when examining the data associated with the participants who were also Peer Fitness Trainers (PFTs). In addition, a significant decrease in countermovement jump (CMJ) height was also observed among both the CON and CEP groups. Thus, it is possible that the general demands associated with the occupation of firefighting itself may influence measures of functional movement and health and fitness among this tactical athlete population to a greater degree than other traditional athlete populations. Accordingly, it is also possible that the demands of the firefighting occupation influenced the measures of functional movement and health and fitness in an acute manner during a given testing session, but not among all testing sessions (e.g., completing their testing session immediately after ending a shift vs. completing their testing session the day after a shift).

Finally, the potential for experimenter error during the functional movement and health and fitness assessments may have influenced the various measures in general. Specifically, it should be noted that the group membership of four total participants (CON = 2, CEP = 2) became un-blinded to the primary researcher of the current study. Due to the lack of availability of a secondary rater to complete the various movement assessments, this knowledge of group membership should be considered a limitation as well. In addition, due to the specific cohort population utilized in this study, the results of the current study are not generalizable outside of the male active-duty firefighter population.

Recommendations for Future Research

Accordingly, future research should examine the influence of compliance during both supervised and non-supervised corrective exercise training programming on changes in functional movement quality and health and fitness outcomes among active-duty firefighters. This could include differing types of supervision as well. For example, no supervision versus supervision by a certified PFT versus another certified practitioner (e.g., certified strength and conditioning specialist, certified personal trainer, etc.) versus a licensed clinician (e.g., athletic trainer, physical therapist). In addition, the influence of various duration lengths of similar corrective exercise programming on changes in functional movement quality and health and fitness should also be investigated. Furthermore, future research should also investigate the potential influence of this corrective exercise training programming on individual sub-tests of the FMS and ME Test, the potential influence initial functional movement quality on these individual sub-tests of the FMS and ME Test, as well this corrective exercise training programming on other movement assessments commonly utilized by practitioners and researchers to assess injury risk among athletes.

The results of the current study also suggest that the criterion-reference validity of the ME Test, in reference to the FMS, may be lacking. As such, from a non-intervention perspective, future research should also examine the potential differing influences of various anthropometric and health and fitness variables on FMS and ME Test score outcomes as it is possible that the FMS and ME Test do not quantify functional movement quality in the same fashion among the active-duty firefighter population. Similarly, future research should also examine general relationships between the FMS and ME Test with other movement assessments, such as the Star Excursion Balance Test (SEBT), the Y-Balance Test (YBT), and/or the Landing Error Scoring System (LESS).

Finally, researchers should also incorporate female active-duty firefighters in these various investigations. While the percentage of women in the occupation of firefighting is quite low at roughly 3.4% (National Fire Protection Association), previous research suggests that the quality of functional movement patterns may differ between sexes (Agresta, Slobodinsky, & Tucker, 2014; Anderson, Neumann, & Huxel Bliven, 2015; Gnacinski, Cornell, Meyer, Arvinen-Barrow, & Earl-Boehm, in press; Knapik, Cosio-Lima, Reynolds, & Shumway, 2015; Letafatkar, Hadadnezhad, Shojaedin, & Mohamadi, 2014; Loudon, Parkerson-Mitchell, Hildebrand, & Teague, 2014). As such, researchers should attempt to examine all of these various areas of future research in regards to the female active-duty firefighter population as well.

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APPENDICES

APPENDIX A

Functional Movement Screen Scoring Criteria

Functional Movement Screen (FMS) Scoring Criteria

Note. All criteria must be met in order to achieve the respective score of each individual FMS sub-test.

Deep Squat

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

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

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

0 = Pain is associated with any portion of the test

Hurdle Step

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

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

1 = Contact between foot and hurdle occurs

0 = Pain is associated with any portion of the test

In-Line Lunge

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

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

1 = Loss of balance is noted

0 = Pain is associated with any portion of the test

Shoulder Mobility

3 = Fists are within one hand length

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

1 = Fists are not within one-and-a-half hand lengths

0 = Pain is associated with any portion of this test or the shoulder mobility clearing exam

Shoulder Mobility Clearing Exam

Individual places palm on opposite shoulder and lifts elbow towards chin.

Active Straight-Leg Raise

3 = Vertical line of the malleolus resides between mid-thigh and anterior superior iliac spine (ASIS); Non-moving limb remains in neutral position

2 = Vertical line of the malleolus resides between mid-thigh and joint line; Non-moving limb remains in neutral position

1 = Vertical line of the malleolus resides below joint line; Non-moving limb remains in neutral position

0 = Pain is associated with any portion of the test

Trunk Stability Push-Up

3 = Body lifts as a unit with no lag in the spine
Men: perform repetition with thumbs aligned with the top of the head
Women: perform repetition with thumbs aligned with the chin

2 = Body lifts as a unit with no lag in the spine
Men: perform repetition with thumbs aligned with the chin
Women: perform repetition with thumbs aligned with the clavicle

1 = Unable to lift body as a unit with no lag in the spine
Men: thumbs aligned with the chin
Women: thumbs aligned with the clavicle

0 = Pain is associated with any portion of this test or the spinal extension clearing exam

Spinal Extension Clearing Exam

Individual performs a press-up in the push-up position (i.e., a “cobra stretch”).

Rotary Stability

3 = Performs a correct unilateral repetition

2 = Performs a correct diagonal repetition

1 = Inability to perform a diagonal repetition

0 = Pain is associated with any portion of this test or the spinal flexion clearing exam

Spinal Flexion Clearing Exam

Individual first assumes the quadruped position (i.e., on hands and knees). The individual then rocks backwards, touching their buttocks to their heels and their chest to their thighs, and reaching their hands out as far as possible (i.e., “child’s pose”).

Adapted from “Movement: Functional Movement Systems – Screening, Assessment and Corrective Strategies, Appendix 9” by G. Cook, 2010, Santa Cruz, CA: On Target Publications, pp. 373–379.

APPENDIX B

Functional Movement Screen Scoring Form

ID #: **Date:**

Functional Movement Screen

Test	Raw Score	Final Score	Notes
1. Deep Squat • Torso // with tibia or toward vertical • Femur < HZ • Knees over feet • Dowel over feet			
2. Hurdle Step • Hips, knees, ankles aligned in sagittal plane • Min. movement of L-spine • Dowel and hurdle remain // • Loss of balance or contact w/hurdle = 1 ***Record Height of Band =***	**R (stepping)** **L**		
3. In-Line Lunge • Dowel remains in contact w/L-ext • No torso movement • Dowel & feet remain in sagittal plane • Knee touches board behind heel	**R (front)** **L**		
4. Shoulder Mobility ***Impingement Clearing (NO = pain)*** ***Right YES NO Left YES NO*** • Fists w/in 1 hand length = 3 • Fists w/in 1.5 units = 2 • Fists > 1.5 units = 1	**R (flexed)** **L**		Record Measured Hand Length =
5. Active SLR • Dowel at mid-thigh (bt patella & ASIS) • Dowel at superior patella • Dowel at inferior patella	**R** **L**		
6. Trunk Stability PU ***Spinal Ext Clearing (NO = pain) YES NO*** • Males: 1 rep w/thumbs at top of forehead then chin • Females: 1 rep w/thumbs at chin then clavicle			

7. Rotary Stability ***Spinal Flex Clearing (NO = pain) YES NO*** • 1 correct unilateral rep w/spine // to board • Knee & elbow touch • II = diagonal	**R (upper moving)** **L**		

TOTAL SCORE = _____ / 21

APPENDIX C

Movement Efficiency Test Checklist

Movement Efficiency (ME) Test Checklist

Test Pattern	Subject Positioning	Tester Instructions / Actions
2-Leg Squat	- Feet shoulder-width apart - Toes pointing straight ahead - Arms extended overhead	- Perform 5 squats as if sitting into chair - Observe: front, side, & back views
2-Leg Squat with Heel Lift	- Elevate heels approximately 2” - Feet shoulder-width apart - Toes pointing straight ahead - Arms extending overhead	- Perform 5 squats as if sitting into chair - Observe: front, side, & back views
1-Leg Squat (bilateral)	- Individual balances on 1-leg - Toes pointing straight ahead - Place hands on hips - Non-involved foot & leg are neutral	- Perform 5 squats as if sitting into chair - Observe: front, side, & back views
Push-Up	- Assume a push-up position - Hands outside shoulders, even with chest - Head looking at ground	- Perform 5-10 push-ups - Observe: Side view
Shoulder Movements (4 total movements completed bilaterally)	- Standing with back to wall - Feet hip-width apart, arms by sides - Heels, buttocks, shoulders & back of head touch wall	- Raise arm straight overhead - Elbows at 90°, rotate shoulder taking back of wrist to wall - Elbows at 90°, rotate shoulder taking wrists forward toward mid-line of body - Hands together in front of body, reach back of wrist to wall **ALL of the above:** Observe front & side views; perform one arm at a time
Trunk Movements (2 total movements completed bilaterally)	- Stand with back to wall - Feet shoulder-width apart, arms by sides	- Lateral Flexion: Side bend and slide hand down outside of leg

	- Heels, buttocks, shoulders, & back of head touch wall - Rotation: Subject steps away from wall, places hands across shoulders	- Rotation: Rotate upper body one direction as far as possible **ALL of the above:** Observe front & side views; perform movement in each direction
Cervical Movements (2 total movements completed bilaterally)	- Feet shoulder-width apart, arms by sides	- Lateral Flexion: Tip head, taking ear to shoulder - Rotation: Rotate head and look over shoulder **ALL of the above:** Observe front & side views; perform movement in each direction

Adapted from “Fusionetics Movement Efficiency Test Protocol Guide.” Retrieved from http://resourcecenter.fusionetics.com/wp-content/uploads/Customer%20Resources%20(facility)/Test%20Protocol%20Guides/Test-Protocol-Guide_ME-Test_-with-videoc.pdf

APPENDIX D

Movement Efficiency Test Scoring Form

FUSIONETICS™ MOVEMENT EFFICIENCY (ME) TEST

Name: ______________________ Date: ____/____/____

2-LEG SQUAT

CHECKPOINT	COMPENSATION	RIGHT	LEFT
VIEW: FRONT			
Foot/Ankle	Foot Turns Out		
	Foot Flattens		
Knee	Knee Moves In (Valgus)		
	Knee Moves Out (Varus)		
VIEW: SIDE			
L-P-H-C	Excessive Forward Lean		
	Low Back Arches		
	Low Back Rounds		
Shoulder	Arms Fall Forward		
VIEW: BACK			
Foot/Ankle	Heel of Foot Lifts		
L-P-H-C	Asymmetrical Weight Shift		

2-LEG SQUAT WITH HEEL LIFT

CHECKPOINT	COMPENSATION	RIGHT	LEFT
VIEW: FRONT			
Foot/Ankle	Foot Turns Out		
	Foot Flattens		
Knee	Knee Moves In (Valgus)		
	Knee Moves Out (Varus)		
VIEW: SIDE			
L-P-H-C	Excessive Forward Lean		
	Low Back Arches		
	Low Back Rounds		
Shoulder	Arms Fall Forward		
VIEW: BACK			
L-P-H-C	Asymmetrical Weight Shift		

1-LEG SQUAT

CHECKPOINT	COMPENSATION	RIGHT	LEFT
VIEW: FRONT			
Foot/Ankle	Foot Flattens		
Knee	Knee Moves In (Valgus)		
	Knee Moves Out (Varus)		
L-P-H-C	Uncontrolled Trunk: Flexion, Rotation, and/or Hip Shift		
	Loss of Balance		

PUSH-UP

CHECKPOINT	COMPENSATION	
VIEW: SIDE		
Spine	Head Moves Forward	
	Scapular Winging	
L-P-H-C	Low Back Arches/Stomach Protrudes	
Knees	Knees Bend	

SHOULDER MOVEMENTS

CHECKPOINT	COMPENSATION	RIGHT	LEFT
VIEW: SIDE			
Shoulder	Flexion: Compensation during movement / unable to bring hand to wall		
	Internal Rotation: Compensation during movement / unable to bring hand to mid-line of trunk		
	External Rotation: Compensation during movement / unable to bring hand to wall		
	Horizontal Abduction: Compensation during movement / unable to bring hand to wall		

TRUNK/LUMBAR SPINE MOVEMENTS

CHECKPOINT	COMPENSATION	RIGHT	LEFT
VIEW: FRONT			
Spine	Trunk Lateral Flexion: Compensation during movement / unable to touch lateral joint line of knee		
	Trunk Rotation: Compensation during movement / unable to rotate shoulder to mid-line		

CERVICAL SPINE MOVEMENTS

CHECKPOINT	COMPENSATION	RIGHT	LEFT
VIEW: FRONT			
Spine	Lateral Flexion: Compensation during movement / unable to side-bend half the distance to shoulder		
	Rotation: Compensation during movement / unable to rotate chin to shoulder		

NOTES	ASSESSMENT	PLAN

Practitioner Printed Name: ______________ Practitioner Signature: ______________

APPENDIX E

Institutional Review Board Protocol Approval

UNIVERSITY of WISCONSIN
UWMILWAUKEE

Department of University Safety & Assurances

Melissa Spadanuda
IRB Manager
Institutional Review Board
Engelmann 270
P. O. Box 413
Milwaukee, WI 53201-0413
(414) 229-3173 *phone*
(414) 229-6729 *fax*

http://www.irb.uwm.edu
spadanud@uwm.edu

New Study - Notice of IRB Expedited Approval

Date: July 2, 2015

To: Kyle Ebersole, PhD
Dept: Kinesiology

Cc: David Cornell

IRB#: 15.389
Title: Influence of a Corrective Exercise Training Program on Measures of Functional Movement Among Active-Duty Firefighters

After review of your research protocol by the University of Wisconsin – Milwaukee Institutional Review Board, your protocol has been approved as minimal risk Expedited under Category 4 and 7 as governed by 45 CFR 46.110. Your protocol has been granted approval to waive documentation of informed consent as governed by 45 CFR 46.117 (c).

This protocol has been approved on **July 2, 2015** for one year. IRB approval will expire on **July 1, 2016**. If you plan to continue any research related activities (e.g., enrollment of subjects, study interventions, data analysis, etc.) past the date of IRB expiration, a continuation for IRB approval must be filed by the submission deadline. If the study is closed or completed before the IRB expiration date, please notify the IRB by completing and submitting the Continuing Review form found in IRBManager.

Any proposed changes to the protocol must be reviewed by the IRB before implementation, unless the change is specifically necessary to eliminate apparent immediate hazards to the subjects. It is the principal investigator's responsibility to adhere to the policies and guidelines set forth by the UWM IRB, maintain proper documentation of study records and promptly report to the IRB any adverse events which require reporting. The principal investigator is also responsible for ensuring that all study staff receive appropriate training in the ethical guidelines of conducting human subjects research.

As Principal Investigator, it is your responsibility to adhere to UWM and UW System Policies, and any applicable state and federal laws governing activities which are independent of IRB review/approval (e.g., FERPA, Radiation Safety, UWM Data Security, UW System policy on Prizes, Awards and Gifts, state gambling laws, etc.). When conducting research at institutions outside of UWM, be sure to obtain permission and/or approval as required by their policies.

Contact the IRB office if you have any further questions. Thank you for your cooperation and best wishes for a successful project.

Respectfully,
Melissa C. Spadanuda
IRB Manager

APPENDIX F

Recruitment Flyer

RESEARCH STUDY PARTICIPANTS NEEDED!

A study investigating the influence of a corrective exercise training program on functional movement quality among active-duty firefighters is being conducted by researchers at the University of Wisconsin-Milwaukee

- **Eligible Participants Include:**
  - Firefighters who are cleared for active-duty work & have been an active-duty firefighter for at least 12 months (i.e., 1 year)
  - Individuals who:
    - Do not have a heart condition or any chest pain
    - Do not suffer from dizziness
    - Are not currently pregnant

- $100 gift cards will be awarded to participants who complete all aspects of the study

- Participants will be broken up into 2 groups – Corrective Exercise Program (CEP) Group & Control (CON) Group
  - CEP Group = will complete a 4-week corrective exercise program intervention
  - CON Group = deferred treatment for 4 weeks, **then will start to receive the same corrective exercise program intervention at Week 5**
- Functional Movement Data will be collected at Week 0 (pre-intervention), Week 2 (mid-intervention), and Week 5 (post-intervention)
  - Fusionetics Movement Efficiency (ME) Test
  - Functional Movement Screen (FMS)
  - Joint Ranges of Motion
- Health & Fitness Data will be collected at Week 0 (pre-intervention) and Week 5 (post-intervention)
  - Total Body Power
  - Lower Extremity Muscular Strength
  - Core Muscular Endurance

Please contact David Cornell (dcornell@uwm.edu) if you are interested in participating or looking for more information. Testing sessions will be conducted at Station #5 (1313 W. Reservoir Avenue, Milwaukee, WI 53205). **All individual data will be kept completely confidential** (i.e., not given to the fire department).

Corrective Exercise Research Study David Cornell **dcornell@uwm.edu**

Corrective Exercise Research Study David Cornell **dcornell@uwm.edu**

Corrective Exercise Research Study David Cornell **dcornell@uwm.edu**

Corrective Exercise Research Study David Cornell **dcornell@uwm.edu**

Corrective Exercise Research Study David Cornell **dcornell@uwm.edu**

Corrective Exercise Research Study David Cornell **dcornell@uwm.edu**

Corrective Exercise Research Study **David Cornell** **dcornell@uwm.edu**

APPENDIX G

Criteria for Inclusion Questionnaire

Human Performance & Sport Physiology Laboratory
Integrative Health Care & Performance Unit
Department of Kinesiology
College of Health Sciences
University of Wisconsin-Milwaukee
3409 N. Downer Ave
Pavilion – Physical Therapy Suite, Room 365
Milwaukee, WI 53211-2956

ID#: ____________________

Criteria for Inclusion Questionnaire

Study Title: *Influence of a Corrective Exercise Training Program on Measures of Functional Movement Among Active-Duty Firefighters*

The following questions will help determine if you meet the eligibility criteria for this study. It is important that you accurately answer each question.

Please answer the following questions with a YES or NO response	YES	NO
1. Are you fluent in speaking and writing English?		
2. Are you at least 18 years of age?		
3. Are you an active-duty firefighter?		
4. Are you currently cleared by your department for full active-duty work?		
5. Have you been an active-duty firefighter for at least 12 months (i.e., 1 year)?		

Eligible to Participate in Phase 1:

YES NO

The following questions will help determine if you meet the criteria for inclusion for Phase 1 of this study. It is important that you accurately answer each question.

Please answer the following questions with a YES or NO response	YES	NO
6. Have you been diagnosed with a heart condition?		
7. Do you feel pain in your chest, feel faint, or have severe spells of dizziness, when you engage in physical activity?		
8. Are you currently pregnant?		
9. Do you know of any reason why you should not engage in exercise or physical activity or participate in this study?		

Eligible to Participate in Phase 2:
YES NO

The following questions will help determine if you meet the criteria for inclusion for Phase 2 of this study. It is important that you accurately answer each question.

Please answer the following questions with a YES or NO response	**YES**	**NO**
10. Are you <u>currently</u> following any type of structured corrective exercise program?		
11. Have you had any serious symptomatic ankle, knee, hip, back, or shoulder trauma that required medical attention within the last 3 months?		
12. Have you had any surgery on your ankle, knee, hip, back, or shoulder within the last year (i.e., 12 months)?		
13. Do you have any bone, joint, or muscle abnormalities (e.g., torn rotator cuff) that require medical attention?		
14. Do you have previous experience using the Fusionetics Human Performance System and its online platform?		
15. Have you ever completed a Movement Efficiency Test through the Fusionetics Human Performance System?		
16. Have you ever followed a corrective exercise program based on the Fusionetics Movement Efficiency Test?		

APPENDIX H

Demographics Questionnaire

Study Title:
Influence of a Corrective Exercise Training Program on Measures of Functional Movement Among Active-Duty Firefighters
IRB Protocol # = 15.389

Please indicate your responses to the following items.

1. **Gender**

2. **Ethnicity (cultural background)**

3. **Age**

4. **Please indicate your highest level of education attained**

   a. Some high school education

   b. High school diploma

   c. Post-high school education

   d. Bachelor's degree

   e. Other

   If you chose **Other**, please explain what level of education you have attained

5. **How would you describe the area in which you live?**

   a. Urban

   b. Suburban

   c. Rural

6. **Which fire department do you belong to AND what firehouse are you <u>primarily</u> stationed at?**

7. **Years of firefighting experience**

8. **Current rank (ex: cadet, recruit, lieutenant, captain, etc.)**

9. In the last 6 months, what activity have you done most often for exercise?

Walk Swim Bike Run Elliptical or Similar Resistance Training Other

If you answered **Other**, what is the primary other activity that you have done?

10. Which of the following best describes your level of physical activity that you have engaged in over the last 6 months:

a. <100 minutes of moderate activity per week

b. 100-150 minutes of moderate activity per week

c. >150 minutes of moderate activity per week

d. >75 minutes of vigorous activity per week

11. Have you ever performed the following exercises and/or activities?

a.	Vertical Jump	YES	NO
b.	Jackson Strength System	YES	NO
c.	Plank Holds	YES	NO
d.	Functional Movement Screen (FMS)	YES	NO
e.	Fusionetics Movement Efficiency Test (ME Test)	YES	NO
f.	Y-Balance Test (i.e., Single Leg Balance Test)	YES	NO

14. Have you ever engaged in a corrective exercise program before?

If so, how many weeks did you comply with this program?

When did you stop engaging in this program?

APPENDIX I

Corrective Exercise Equipment

Corrective Exercise Equipment

1 set of Resistance Bands (yellow, red, blue, green, & black)
*Including 2 handles, 1 ankle strap, & 1 door anchor

1 set of flat Thera-Bands (yellow, blue, green)
*Including 1 door anchor

1 Stretching Strap

1 Stability Ball (with pump)

1 Exercise Mat

APPENDIX J

Compliance Questionnaire

Human Performance & Sport Physiology Laboratory
Integrative Health Care & Performance Unit
Department of Kinesiology
College of Health Sciences
University of Wisconsin-Milwaukee
3409 N. Downer Ave
Pavilion – Physical Therapy Suite, Room 365
Milwaukee, WI 53211-2956

ID #: ________________

COMPLIANCE QUESTIONNAIRE

Study Title: *Influence of a Corrective Exercise Training Intervention on Measures of Functional Movement Among Active-Duty Firefighters*

Intervention Week: _______

Corrective Exercise Programming (date)	Approximate Time Spent Exercising (min)
Day 1:	
Day 2:	
Day 3:	

If you were not able to complete all 3 days of your corrective exercise programming, is there a specific reason why?

Did you perform any other exercise this week? If so, what kinds? How intense (e.g., duration, reps, sets, weight, etc.) was this exercise?

APPENDIX K

Exercise History Questionnaire

Human Performance & Sport Physiology Laboratory
Integrative Health Care & Performance Unit
Department of Kinesiology
College of Health Sciences
University of Wisconsin-Milwaukee
3409 N. Downer Ave
Pavilion – Physical Therapy Suite, Room 365
Milwaukee, WI 53211-2956

ID #: ________________

Date: ________________

EXERCISE HISTORY QUESTIONNAIRE

Study Title: *Influence of a Corrective Exercise Training Intervention on Measures of Functional Movement Among Active-Duty Firefighters*

1. During the past 3 months, how many days per week have you spent performing moderate to strenuous exercise training activities?

0 1 2 3 4 5 6 7

2. How long (minutes) has each exercise training session typically been?

Less than 5 5-19 20-30 More than 30 N/A

3. How high of an intensity level would you say your exercise training has been?

Easy Moderate Somewhat Hard Hard N/A

4. What type resistance training exercise modality do most often utilize?

Running Elliptical Bicycling Free Weights Machine Weights Other N/A

5. If you answered **Other** for question 4, what is the primary other activity that you utilize?

6. Have you engaged in a corrective exercise program in the past 6 months? Yes No

7. If **yes** for Question 6, how many days per week did you perform these corrective exercises?

1 2 3 4 5 6 7

8. If **yes** for Question 6, why did you discontinue this corrective exercise programming?

9. Have you (or are you currently) trained/competed for a sport or other competitive physical activity (e.g., a marathon) in the last year? Yes No

10. Did you compete in an organized, competitive sport at one point of your life? Yes No

11. If **yes** for Question 10, what type of sport and what position (or event) did you play (if applicable)?

Sport: ____

Position: ____

David J. Cornell, PhD, CSCS, CES, EP-C, TSAC-F

CURRICULUM VITAE

CONTACT INFORMATION

Human Performance & Sport Physiology Laboratory
Integrative Health Care & Performance Unit
Department of Kinesiology
College of Health Sciences
University of Wisconsin-Milwaukee

Address: Pavilion – Physical Therapy, Suite 350
3409 N. Downer Ave
Milwaukee, WI 53211-2956
Office: Pavilion, Room 375
Email: dcornell@uwm.edu
Office Phone: 414-229-3364

FORMAL EDUCATION

(2018) **DPT** **Doctor of Physical Therapy**, *University of Wisconsin-Milwaukee*, Milwaukee, WI

2016 **PhD** **Health Sciences**, *University of Wisconsin-Milwaukee*, Milwaukee, WI
Concentration: Kinesiology
Specialization: Integrative Health Care & Performance
Adviser: Kyle T. Ebersole, PhD, LAT, PES
Dissertation Title: "Influence of a Corrective Exercise Training Program on Measures of Functional Movement Among Active-Duty Firefighters"
Preliminary Examination Grant Title: "Heart Rate Variability: An Innovative Approach to Examining Autonomic Nervous System Function Among Active-Duty Firefighters"

2012 **MS** **Kinesiology**, *University of Wisconsin-Milwaukee*, Milwaukee, WI
Concentration: Exercise Physiology
Secondary Area: Sport Psychology
Tertiary Area: Motor Control
Adviser: Kyle. T. Ebersole, PhD, LAT, PES
Thesis Title: "Relationship Between Counter Movement Jump Performance and Extraversion Level"

2010 **BS** **Exercise Science**, *Carroll University*, Waukesha, WI
Minors: Sports Nutrition, Psychology, Business Management

PROFESSIONAL EXPERIENCE

Academic Experience

Course Lecturer, BS Kinesiology Program, Department of Kinesiology, College of Health Sciences, *University of Wisconsin-Milwaukee*, Milwaukee, WI (Spring 2013 – present)

Laboratory Assistant, DPT Program, Department of Kinesiology, College of Health Sciences, *University of Wisconsin-Milwaukee*, Milwaukee, WI (Fall 2014 – present)
Laboratory Assistant, Graduate Kinesiology Programs, Department of Kinesiology, College of Health Sciences, *University of Wisconsin-Milwaukee*, Milwaukee, WI (Fall 2011 – 2013)
Teaching Assistant, BS Kinesiology Program, Department of Kinesiology, College of Health Sciences, *University of Wisconsin-Milwaukee*, Milwaukee, WI (Fall 2011 – Summer 2012)

Clinical Experience

Student Physical Therapist Intern, *Peak Performance Physical Therapy & Sports Medicine*, Appleton, WI (January 2016)
Corrective Exercise Specialist, Performance & Injury Clinic, Department of Kinesiology, College of Health Sciences, *University of Wisconsin-Milwaukee*, Milwaukee, WI (March 2012 – May 2014)

Practitioner Experience

Certified Strength & Conditioning Specialist, Human Performance and Sport Physiology Laboratory, Department of Kinesiology, College of Health Sciences, *University of Wisconsin-Milwaukee*, Milwaukee, WI (September 2010 – present)
Personal Trainer, *La Casa de Esperanza Fitness Center*, Waukesha, WI (March 2009 – January 2010)
Strength & Conditioning Coach/Intern, Athletics Department, *Muskego High School*, Muskego, WI (June 2009 – August 2009)
Strength & Conditioning Coach/Intern, Women's Volleyball Team, *Carroll University*, Waukesha, WI (February 2009 – April 2009)
Student/Intern Personal Trainer, Ganfield Fitness Center, *Carroll University*, Waukesha, WI (September 2008 – November 2008)

RESEARCH PROJECT INVOLVEMENT

Primary Investigator (PI), Human Performance & Sport Physiology Laboratory, Department of Kinesiology, *University of Wisconsin-Milwaukee*, Milwaukee, WI

- *Influence of a Corrective Exercise Training Program on Measures of Functional Movement Among Active-Duty Firefighters* (2015 – present). IRB Protocol Number: 15.389
- *Acute Effects of Self-Myofascial Release on Isometric Strength and Electro-Mechanical Aspects of Muscle Function* (2014 – present). IRB Protocol Number: 14.412
- *Differences in Muscle Activation and Other Physiological Measures Between Sandbag and Dumbbell Resistance Exercise* (2013 – 2014). IRB Protocol Number: 13.407
- *Relationship Between Counter Movement Jump Performance and Extraversion Level* (2012 – 2013). IRB Protocol Number: 12.293

Co-Primary Investigator (co-PI), Human Performance & Sport Physiology Laboratory, Department of Kinesiology, *University of Wisconsin-Milwaukee*, Milwaukee, WI

- *Reliability of a Movement Screening Tool* (2015 – present). PIs: Kyle T. Ebersole & David J. Cornell. IRB Protocol Number: 15.295
- *Heart Rate Variability in Professional Baseball Players* (2013 – present). PIs: Kyle T. Ebersole & David J. Cornell. IRB Protocol Number: 13.249

- *Occupational Athletes: An Integrated Approach to Firefighting Performance* (2012 – present). PIs: Kyle T. Ebersole, David J. Cornell, Stacy L. Gnacinski, & Barbara B. Meyer. IRB Protocol Number: 13.180

Co-Investigator (co-I), Department of Kinesiology, *University of Wisconsin-Milwaukee*, Milwaukee, WI

- *Decreasing Sport Injury Risk and Improving Student-Athlete Quality of Life and Performance: A Preliminary Investigation of an Inter-Professional Performance Enhancement Program* (2014 – 2015). PIs: Jennifer E. Earl-Boehm & Monna Arvinen-Barrow. IRB Protocol Number: 15.008

Graduate Student Research Assistant, Human Performance & Sport Physiology Laboratory, Department of Kinesiology, *University of Wisconsin-Milwaukee*, Milwaukee, WI

- *Biopsychosocial Characteristics of Experienced and Novice Marathon Runners* (2012). PIs: Kyle T. Ebersole & Barbara B. Meyer. IRB Protocol Number: 12.290
- *Effect of Lower Extremity Muscle Massage on Attitude and Anxiety* (2011). PIs: Kyle T. Ebersole & Barbara B. Meyer. IRB Protocol Number: 11.272
- *The Effect of Exhaustive Cycling on Cognitive Function* (2011). PIs: Kyle T. Ebersole & Wendy E. Huddleston

Graduate Student Research Assistant, *Medical College of Wisconsin*, Milwaukee, WI

- *Effects of Exercise on Brain Function and Metabolic Profile in Mild Cognitive Impairment* (2011). PI: J. Carson Smith. Study Number: PRO00010783

PUBLICATIONS & SCHOLARSHIP

<u>Research Manuscripts in Publication (refereed journals)</u>

1. **Cornell, D.J.**, Paxson, J.L., Caplinger, R.A., Seligman, J.R., Davis, N.A., Flees, R.J., & Ebersole, K.T. (in press). In-game heart rate responses among professional baseball starting pitchers. *Journal of Strength and Conditioning Research*.
2. Gnacinski, S.L., **Cornell, D.J.**, Meyer, B.B., Arvinen-Barrow, M., & Earl-Boehm, J.E. (in press). Functional Movement Screen™ factorial validity and measurement invariance across sex among collegiate student-athletes. *Journal of Strength and Conditioning Research*.
3. Gnacinski, S.L., Meyer, B.B, Hess, C.W., **Cornell, D.J.**, Mims, J., Zamzow, A., & Ebersole, K.T. (in press). The psychology of firefighting: An examination of psychological skills use among firefighters. *Journal of Performance Psychology*.
4. **Cornell, D.J.**, Gnacinski, S.L., Zamzow, A., Mims, J., & Ebersole, K.T. (in press). Measures of health, fitness, and functional movement among firefighter recruits. *International Journal of Occupational Safety and Ergonomics*.
5. **Cornell, D.J.**, Gnacinski, S.L., Zamzow, A., Mims, J., & Ebersole, K.T. (in press). Influence of obesity on movement efficiency among firefighter recruits. *Work*.
6. Gnacinski, S.L., Ebersole, K.T., **Cornell, D.J.**, Mims, J., Zamzow, A., & Meyer, B.B. (in press). Firefighters' cardiovascular health and fitness: An assessment of heart rate recovery and maximal oxygen uptake training adaptations that occur during firefighter training academies. *Work*.

7. Gnacinski, S.L., Meyer, B.B., **Cornell, D.J.**, Mims, J., Zalewski, K.R., & Ebersole, K.T. (2015). Tactical athletes: An integrated approach to understanding and enhancing the health and performance of firefighters-in-training. *International Journal of Exercise Science*, *8*(4), 341–357.
8. **Cornell, D.J.**, Ebersole, K.T., Meyer, B.B., & Zalewski, K.R. (2015). Relationships between extraversion and measures of counter movement jump performance. *International Journal of Sports Science*, *5*(3), 73–79.
9. **Cornell, D.J.**, Gnacinski, S.L., Langford, M.H., Mims, J., & Ebersole, K.T. (2015). Backwards overhead medicine ball throw and counter movement jump performance among firefighter candidates. *Journal of Trainology*, *4*(1), 11–14.

Professional Development Manuscripts in Publication (refereed journals/reports)

1. **Cornell, D.J.**, Ebersole, K.T., & Mims, J. (2015). Tire flipping: A method of assessing functional power output among firefighters. *NSCA TSAC Report*, *37*, 4–6.

Published Interviews

1. Fitness program improves firefighter safety. *UWM Research Report*, 2016. http://uwm.edu/researchreport/communityhealth-and-personalwellness/firefighter/
2. CHS graduate students shine in leadership roles. *CHS e-Chronicle*, October 9, 2015. http://uwm.edu/healthsciences/news/chs-graduate-students-shine-in-leadership-roles/
3. Asp, K. (2015). Speed sculpt with sand. *Shape Magazine*, March issue, pg. 89-96.
4. Easter, M. (2014). Hey dumbbell, try a sandbag. *Men's Health Magazine*, April issue, pg. 38.
5. Johannes, L. (2014). Weightlifting with shifting sand: Do sandbags offer a more complete workout? *The Wall Street Journal: Life and Culture*, March 3. http://online.wsj.com/news/articles/SB10001424052702304360704579417141446599718?mg=reno64-wsj&url=http%3A%2F%2Fonline.wsj.com%2Farticle%2FSB10001424052702304360704579417141446599718.html

PROFESSIONAL & ACADEMIC PRESENTATIONS

National Presentations

1. **Cornell, D.J.**, Ebersole, K.T., & Ford, E.E. (2016). Influence of an acute bout of self-myofascial release on the expression of isometric knee extension force and electromyographic and mechanomyographic signals of the quadriceps musculature. Poster to be presented at the International Society of Electromyography and Kinesiology World Congress, Chicago, IL, USA.
2. **Cornell, D.J.**, & Ebersole, K.T. (2016). Inter-rater reliability of a movement efficiency test among the firefighter cadet population. Poster to be presented at the American College of Sports Medicine Annual Meeting, Boston, MA, USA, June 1.
3. Ebersole, K.T., & **Cornell, D.J.** (2016). Inter-rater response stability of a movement efficiency test among the firefighter cadet population. Poster to be presented at the American College of Sports Medicine Annual Meeting, Boston, MA, USA, June 1.
4. **Cornell, D.**, Flees, R., Caplinger, R., Seligman, J., Paxson, J., Davis, N., & Ebersole, K. (2015). Influence of home and away starts on in-game heart rate responses among professional baseball starting pitchers. *Journal of Strength and Conditioning Research*, *30*(S1), S76–S77. Poster presented at the National Strength and Conditioning Association National Conference, Orlando, FL, USA, July 10.

5. Kelley, K., Poel, D., **Cornell, D.**, Gnacinski, S., Hess, C., O'Connor, M., Zander, R., Arvinen-Barrow, M., Truebenbach, C., & Earl-Boehm, J. (2015). Identifying sport and gender differences in the Lower Extremity Functional Test (LEFT). *Journal of Athletic Training*, *50*(6S), S-193. Poster presented at the National Athletic Trainers' Association Annual Meeting and Clinical Symposium, St. Louis, MO, USA, June 26.
6. O'Connor, M., **Cornell, D.**, Gnacinski, S., Hess, C., Kelley, K., Poel, D., Zander, R., Arvinen-Barrow, M., Truebenbach, C., & Earl-Boehm, J. (2015). Relationship between hip strength and dynamic balance performance. *Journal of Athletic Training*, *50*(6S), S-267. Poster presented at the National Athletic Trainers' Association Annual Meeting and Clinical Symposium, St. Louis, MO, USA, June 24.
7. **Cornell, D.J.**, Ebersole, K.T., Caplinger, R.A., Seligman, J.R., Paxson, J.L., & Davis, N.A. (2015). Influence of pitching rotation day on resting heart rate variability among professional baseball starting pitchers. *Medicine and Science in Sports and Exercise*, *47*(5S), 49. Poster presented at the American College of Sports Medicine Annual Meeting, San Diego, CA, USA, May 27.
8. Gnacinski, S.L., Ebersole, K.T., **Cornell, D.J.**, Mims, J., & Meyer, B.B. (2015). The psychology of firefighting: An examination of psychological skills use among firefighters. *Medicine and Science in Sports and Exercise*, *47*(5S), 812. Poster presented at the American College of Sports Medicine Annual Meeting, San Diego, CA, USA, May 29.
9. Gnacinski, S.L., Meyer, B.B., **Cornell, D.J.**, Zamzow, A., & Ebersole, K.T. (2014). Examining the effect of a training program on the perceptions of stress and recovery among firefighter recruits. Oral presentation at the annual meeting of the Association for Applied Sport Psychology, Las Vegas, NV, USA, October 17.
10. **Cornell, D.J.**, Ebersole, K.T., Gnacinski, S.L., Gayhart, S.B., Sanger, P.J., & Mims, J. (2014). Predicting "failing" Functional Movement Screen™ scores utilizing the Y-balance test among active firefighters and candidates. *Medicine and Science in Sports and Exercise*, *46*(5S), 118. Poster presented at the American College of Sports Medicine Annual Meeting, Orlando, FL, USA, May 28.
11. Ebersole, K.T., Gnacinski, S.L., **Cornell, D.J.**, Gayhart, S.G., Sanger, P.J., & Mims, J. (2014). The influence of firefighter training academies on measures of fitness and performance. *Medicine and Science in Sports and Exercise*, *46*(5S), 118. Poster presented at the American College of Sports Medicine Annual Meeting, Orlando, FL, USA, May 28.
12. Thorp, L.A., Ebersole, K.T., Gayhart, S.B., **Cornell, D.J.**, Gnacinski, S.L., Morgan, A.J., Conlon, J.K., Sanger, P.J., & Mims, J. (2014). Using the Functional Movement Screen™ to assess performance in the occupational athlete. Poster presented at the National Conference on Undergraduate Research, Lexington, KY, USA, April 4.
13. Van Dorin, A.I., Ebersole, K.T., **Cornell, D.J.**, Gnacinski, S.L., Gayhart, S.B., Sanger, P.J., & Mims, J. (2014). Y-test determination of injury preventiveness within Milwaukee firefighter recruits. Poster presented at the National Conference on Undergraduate Research, Lexington, KY, USA, April 4.
14. Gnacinski, S.L., Ebersole, K.T., Meyer, B.B., & **Cornell, D.J.** (2013). Occupational athletes: Moving toward an integrated approach to enhancing firefighting performance. Poster presented at the annual meeting of the Association for Applied Sport Psychology, New Orleans, LA, USA, October 3.
15. **Cornell, D.J.**, Ebersole, K.T., Meyer, B.B., & Zalewski, K.R. (2013). Relationship between personality and counter movement jump performance. *Medicine and Science in Sports and Exercise*, *45*(5S), 540. Poster presented at the American College of Sports Medicine Annual Meeting, Indianapolis, IN, USA, May 31.

16. Ebersole, K.T., Conlon, J.K., **Cornell, D.J.**, Bartz, M., & Meyer, B.B. (2013). The influence of skeletal muscle massage on heart rate variability. *Medicine and Science in Sports and Exercise*, *45*(5S), 34. Poster presented at the American College of Sports Medicine Annual Meeting, Indianapolis, IN, USA, May 29.

Regional Presentations

1. **Cornell, D.J.**, Gnacinski, S.L., Zamzow, A., Mims, J., & Ebersole, K.T. (2014). Influence of firefighter recruit training programs on measures of health and fitness. Poster presented at the American College of Sports Medicine Annual Midwest Chapter Regional Meeting, Merrillville, IN, USA, November 8.
2. **Cornell, D.J.**, Ebersole, K.T., Zander, R.A., Gayhart, S.B., Sanger, P.J., Thorp, L.A., Spaho, E., & Bryant, J.C. (2014). Differences in core stabilizer muscle activity during dumbbell and sandbag lunges. Oral presentation delivered at the National Strength and Conditioning Association Wisconsin State Clinic, Waukesha, WI, USA, April 12.
3. **Cornell, D.J.**, Ebersole, K.T., Meyer, B.B., & Zalewski, K.R. (2013). Relationship between counter movement jump performance and quadricep and hamstring muscle activation. Poster presented at the National Strength and Conditioning Association Wisconsin State Clinic, Waukesha, WI, USA, April 13.

Local Presentations

1. Flees, R.J., Ebersole, K.T., Paxson, J.L., Dine, N., Caplinger, R.A., Seligman, J.R., Drilias, M.J., & **Cornell, D.J.** (2015). Influence of level of professional baseball on resting heart rate variability among starting pitchers across a season. Poster presented at the College of Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 4.
2. Ford, E.E., **Cornell, D.J.**, & Ebersole, K.T. (2015). Influence of self-myofascial release on the expression of isometric knee extension force. Poster presented at the College of Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 4.
3. **Cornell, D.J.**, Gnacinski, S.L., Mims, J., & Ebersole, K.T. (2015). Longitudinal influence of a firefighter recruit training program on measures of muscular strength. Poster presented at the College of Health Sciences Spring Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, May 1.
4. Ford, E.E., Ebersole, K.T., **Cornell, D.J.**, Zander, R.A., & Gnacinski, S.L. (2015). Relationship between balance and measures of fitness and strength in firefighters. Poster presented at the UW-System Symposium for Undergraduate Research and Creative Activity, Milwaukee, WI, USA, April 24.
5. **Cornell, D.J.**, Ebersole, K.T., Gnacinksi, S.L., & Mims, J. (2014). Longitudinal influence of a firefighter recruit training program on measures of obesity. Oral and poster presentation at the College of Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 5.
6. Kelley, K., **Cornell, D.**, Gnacinski, S., Hess, C., O'Connor, M., Poel, D., Zander, R., Earl-Boehm, J., Truebenbach, C., & Arvinen-Barrow, M. (2014). Differences in collegiate athletes' use of psychological strategies in practice and competition: the Panther-PEP study. Poster presented at the College of Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 5.
7. O'Connor, M., **Cornell, D.**, Gnacinski, S., Hess, C., Kelley, K., Poel, D., Zander, R., Arvinen-Barrow, M., Truebenbach, C., & Earl-Boehm, J. (2014). Relationship among hip strength and dynamic balance performance: the Panther-PEP study. Oral and poster presentation at the College of

Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 5.

8. Poel, D., **Cornell, D.**, Gnacinski, S., Hess, C., Kelley, K., O'Connor, M., Zander, R., Arvinen-Barrow, M., Truebenbach, C., & Earl-Boehm, J. (2014). Identifying sport and gender differences in the Lower Extremity Functional Test (LEFT): the Panther-PEP study. Poster presented at the College of Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 5.
9. **Cornell, D.J.**, Ebersole, K.T., Polega, C., Paxson, J., Seligman, J., & Caplinger, R.A. (2014). Resting heart rate variability among professional baseball starting pitchers: Five case studies. Oral presentation and poster presented at the College of Health Sciences Spring Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, May 2.
10. Flees, R.J., Ebersole, K.T., **Cornell, D.J.**, Zander, R.A., Polega, C., Paxson, J., Seligman, J., & Caplinger, R.A. (2014). Does the relationship between work time and heart rate change across inning in professional baseball pitchers? Poster presented at the College of Health Sciences Spring Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, May 2.
11. Grindeland, S.J., Ebersole, K.T., **Cornell, D.J.**, Polega, C., Paxson, J., Seligman, J., & Caplinger, R.A. (2014). Change in heart rate variability in professional baseball pitchers across a five day period. Poster presented at the College of Health Sciences Spring Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, May 2.
12. Langford, M.H., Ebersole, K.T., **Cornell, D.J.**, Gnacinski, S.L., Gayhart, S.B., Sanger, P.J., & Mims, J. (2014). Estimating power production during a tire flip task in firefighter recruits. Poster presented at the College of Health Sciences Spring Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, May 2.
13. Rosinski, J.B., Ebersole, K.T., **Cornell, D.J.**, Zander, R.A., Polega, C., Paxson, J., Seligman, J., & Caplinger, R.A. (2014). Understanding the relationship between work/rest time and pitching heart rate in baseball pitchers. Poster presented at the College of Health Sciences Spring Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, May 2.
14. Thorp, L.A., Ebersole, K.T., **Cornell, D.J.**, Polega, C., Paxson, J., Seligman, J., & Caplinger, R.A. (2014). Relationships between resting heart rate variability and performance measures among professional baseball pitchers. Poster presented at the College of Health Sciences Spring Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, May 2.
15. Zander, R.A., Ebersole, K.T., **Cornell, D.J.**, Gayhart, S.B., Sanger, P.J., Thorp, L.A., Spaho, E., & Bryant, J.C. (2014). Differences in muscle activity between dumbbell and sandbag lunges. Poster presented at the College of Health Sciences Spring Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, May 2.
16. Thorp, L.A., Ebersole, K.T., **Cornell, D.J.**, Polega, C., Paxson, J., Seligman, J., & Caplinger, R.A. (2014). Resting heart rate variability in professional baseball pitchers. Poster presented at the UW-System Symposium for Undergraduate Research and Creative Activity, Milwaukee, WI, USA, April 11.
17. **Cornell, D.J.**, Ebersole, K.T., Gnacinski, S.L., Gayhart, S.B., Sanger, P.J., & Mims, J. (2013). Reach asymmetry on the Y-Balance Test does not predict a "failing" Functional Movement Screen™ score among active firefighters and candidates. Poster presented at the College of Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 6.
18. Flees, R.J., Ebersole, K.T., **Cornell, D.J.**, Gnacinski, S.L., Gayhart, S.B., Sanger, P.J., & Mims, J. (2013). Relationship between muscular strength and muscular endurance tests. Poster presented at the College of Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 6.

19. Gayhart, S.B., Ebersole, K.T., **Cornell, D.J.**, Gnacinski, S.L., Sanger, P.J., & Mims, J. (2013). Relationship between Y-Balance Test scores and BOMB throw, 1RM squat, and sit-and-reach performance. Poster presented at the College of Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 6.
20. Gnacinski, S.L., Ebersole, K.T., **Cornell, D.J.**, Gayhart, S.B., Sanger, P.J., Mims, J., & Meyer, B.B. (2013). Examining the effect of a recruit training program on the heart rate recovery of firefighter recruits. Poster and oral presentation at the College of Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 6.
21. Grindeland, S.J., Ebersole, K.T., **Cornell, D.J.**, Gnacinski, S.L., Gayhart, S.B., Sanger, P.J., & Mims, J. (2013). Factors that influence heart rate maximum in cadet firefighters. Poster presented at the College of Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 6.
22. Sanger, P.J., Ebersole, K.T., **Cornell, D.J.**, Gnacinski, S.L., Gayhart, S.B., & Mims, J. (2013). Measures of power and strength related to firefighter performance. Poster presented at the College of Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 6.
23. Thorp, L.A., Ebersole, K.T., Gayhart, S.B., **Cornell, D.J.**, Gnacinski, S.L., Morgan, A.J., Conlon, J.K., Sanger, P.J., & Mims, J. (2013). Using the Functional Movement Screen™ to assess performance in the occupational athlete. Poster presented at the College of Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 6.
24. Zander, R.A., Ebersole, K.T., **Cornell, D.J.**, Gayhart, S.B., Sanger, P.J., Thorp, L.A., Spaho, E., Bryant, J.C. (2013). Differences in heart rate and estimated energy expenditure between dumbbell and sandbag lunges. Poster presented at the College of Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 6.
25. Sanger, P.J., Ebersole, K.T., **Cornell, D.J.**, Gnacinski, S.L., Morgan, A.J., Conlon, J.K., & Gayhart, S.B. (2013). Functional movement and measures of power and strength in firefighters. Poster presented at the UW-System Symposium for Undergraduate Research and Creative Activity, Milwaukee, WI, USA, April 19.
26. **Cornell, D.J.**, Ebersole, K.T., Meyer, B.B., Gnacinski, S.L., Conlon, J.K., & Morgan, A.J. (2012). Relationship between Functional Movement Screen™ scores and race time among novice and experienced marathon runners. Poster presented at the College of Health Sciences Fall Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, December 7.
27. **Cornell, D.J.**, Ebersole, K.T., Huddleston, W.E., & Earl-Boehm, J.E. (2012). Personality and acute physiological responses to exhaustive cycling. Poster presented at the College of Health Sciences Spring Research Symposium, University of Wisconsin-Milwaukee, Milwaukee, WI, USA, May 4.

GRANT SUBMISSIONS

Funded

1. **Cornell, D.J. [PI]**, & Ebersole, K.T. (2015–2016). *Influence of a Corrective Exercise Intervention on Movement in Firefighters*. Doctoral Research Grant, National Strength and Conditioning Association Foundation (NSCAF), $12,875 [Funded].
2. **Cornell, D.J. [PI]**, & Ebersole, K.T. (2014–2015). *Acute Effects of Self-Myofascial Release on Isometric Strength and Electro-Mechanical Aspects of Muscle Function*. College of Health

Sciences Doctoral Student Research Grant Award, University of Wisconsin-Milwaukee, $2,000 [Funded].

3. **Cornell, D.J. [PI]**, Ebersole, K.T., Meyer, B.B., & Zalewski, K.R. (2012–2013). *Counter Movement Jump Performance Differences Between Introverts and Extraverts*. College of Health Sciences Masters Student Research Grant Award, University of Wisconsin-Milwaukee, $500 [Funded].

Not Funded

1. **Cornell, D.J. [PI]**, & Ebersole, K.T. (2013). *Physiological Performance of Firefighters with and without Personal Protective Equipment*. Doctoral Research Grant, National Strength and Conditioning Association Foundation (NSCAF), $9,900 [Not Funded].

SCHOLARSHIPS & AWARDS

Merit-Based Scholarships

1. Chancellor's Graduate Student Award. (2012–2017). University of Wisconsin-Milwaukee. Awarded: $10,459 – $12,959 per academic year.
2. College of Health Sciences Chancellor's Graduate Student Award. (Fall, 2015). University of Wisconsin-Milwaukee. Awarded: $2,500.
3. College of Health Sciences Scholarship. (2012–2015). University of Wisconsin-Milwaukee. Awarded: $7,270 – $8,781 per academic year.
4. Department of Kinesiology Scholarship. (2012–2015). University of Wisconsin-Milwaukee. Awarded: $3,050 – $3,342 per academic year.

Awards

1. Graduate Student Travel Award. (2015). University of Wisconsin-Milwaukee. "Influence of home and away starts on in-game heart rate responses among professional baseball starting pitchers". Awarded: $450.
2. College of Health Sciences Graduate Student Research Symposium Competition. (Fall 2014). University of Wisconsin-Milwaukee. "Longitudinal influence of a firefighter recruit training program on measures of obesity". Awarded: $150 (3rd place).
3. College of Health Sciences Graduate Student Research Symposium Competition. (Spring 2014). University of Wisconsin-Milwaukee. "Resting heart rate variability among professional baseball starting pitchers: Five case studies". Awarded: $150 (3rd place).
5. *College of Health Sciences Graduate Student Research Symposium Competition.* (Spring, 2014). University of Wisconsin-Milwaukee. $150 (3rd place). "Resting heart rate variability among professional baseball starting pitchers: Five case studies".

MEMBERSHIP IN PROFESSIONAL ORGANIZATIONS

National Strength and Conditioning Association (NSCA), 2010 – present
American College of Sports Medicine (ACSM), 2011 – present
Midwest American College of Sports Medicine (MWACSM) Regional Chapter, 2012 – present
National Academy of Sports Medicine (NASM), 2013 – present
American Physiological Society (APS), 2014 – present
American Physical Therapy Association (APTA), 2015 – present

Orthopaedic Section, 2015 – present
Sports Physical Therapy Section (SPTS), 2015 – present
Sports Performance Enhancement Special Interest Group (SIG) Member, 2016 – present
Tactical Athlete Special Interest Group (SIG) Member, 2016 – present
Research Section, 2015 – present
Wisconsin Physical Therapy Association (WPTA) Chapter, 2015 – present
International Society of Electromyography and Kinesiology (ISEK), 2016 – present

PROFESSIONAL CREDENTIALS & CERTIFICATIONS

Certified Strength and Conditioning Specialist (CSCS), *National Strength and Conditioning Association (NSCA)*
Certification Number: 201071655
Date of Certification: July 12, 2010
Tactical Strength and Conditioning–Facilitator (TSAC-F), *National Strength and Conditioning Association (NSCA)*
Certification Number: 7247990130
Date of Certification: March 20, 2015
Certified Exercise Physiologist (EP-C), *American College of Sports Medicine (ACSM)*
Certification Number: 1027279
Date of Certification: August 18, 2012
Exercise is Medicine (EIM) – Credential Level II, *American College of Sports Medicine (ACSM)*
Date of Credential: March 6, 2015
Corrective Exercise Specialist (CES), *National Academy of Sports Medicine (NASM)*
Certification Number: 1435191
Date of Certification: January 14, 2013
Functional Movement Screen (FMS) – Level I Certified, *Functional Movement Systems*
Date of Certification: June 1, 2012
Dynamic Variable Resistance Training (DVRT) – Level I Certified, *Ultimate Sandbag Fitness System*
Date of Certification: September 19, 2012
Basic Life Support for Healthcare Providers, *American Red Cross*
Current through: November 15, 2017

PROFESSIONAL TRAINING & DEVELOPMENT

Professional Development Workshops & Seminars Attended
Responsible Conduct of Research Seminar, *National Institutes of Health (NIH) / University of Wisconsin-Milwaukee* (Fall 2014)
Graduate Student Workshops, *University of Wisconsin-Milwaukee*
"Developing Your Statement of Teaching Philosophy" (2014)
"Grant Writing Basics: Proposal Writing" (2012)

Conferences & Clinics Attended
American College of Sports Medicine Annual Meeting (2013 – 2015)
Midwest Chapter of the American College of Sports Medicine Annual Regional Meeting (2014)

National Strength and Conditioning Association National Meeting (2015)
National Strength and Conditioning Association Wisconsin State Clinic (2012 – 2015)
National Student Conclave of the American Physical Therapy Association (2014)

TEACHING EXPERIENCE

Courses Taught

Department of Kinesiology, College of Health Sciences, University of Wisconsin-Milwaukee
Principles of Strength and Conditioning (KIN 336)
Undergraduate, BS Kinesiology Program (Spring 2013 – 2016)

Laboratory Assistant

Department of Kinesiology, College of Health Sciences, University of Wisconsin-Milwaukee
Physiological Regulation in Exertion and Disease (KIN 536)
Graduate, Doctor of Physical Therapy (DPT) Program (Fall 2014 – 2015)
Advanced Exercise Physiology (KIN 530)
Graduate, Kinesiology Programs (Fall 2011 – 2013)

Guest Lectures Delivered

Department of Kinesiology, College of Health Sciences, University of Wisconsin-Milwaukee
Health Promotion / Wellness for Physical Therapy Practice (KIN 745)
Graduate, Doctor of Physical Therapy (DPT) Program
Lecture Title: "Movement Screening for the Occupational Athlete" (Spring 2014)
Foundations of Injury Prevention and Performance (KIN 412)
Undergraduate, Athletic Training Education Program (ATEP)
Lecture Title: "Movement Screening 101" (Fall 2015)
Lecture Title: "Olympic Weightlifting 101" (Fall 2012 – 2014)
Therapeutic Exercise & Rehabilitation Techniques in Athletic Training (KIN 414)
Undergraduate, Athletic Training Education Program (ATEP)
Lecture Title: "How to Teach the Power Clean" (Spring 2013)

Graduate Student Teaching Assistant

Department of Kinesiology, College of Health Sciences, University of Wisconsin-Milwaukee
Exercise Physiology (KIN 330)
Undergraduate, BS Kinesiology Program (Summer 2012)
Ethics and Values in the Health and Fitness Professions (KIN 400)
Undergraduate, BS Kinesiology Program (Fall & Spring 2011 – 2012)

SERVICE

PROFESSIONAL SERVICE

Committees

Student Affairs Committee (SAC) At-Large Member, *American College of Sports Medicine* (May 2014 – present)

Research and Education Consortium Member, *National Strength and Conditioning Association* (July 2015 – present)

<u>**Manuscript Peer-Reviewer (refereed journals)**</u>

Journal of Sports Medicine and Physical Fitness (2015 – 2016)

<u>**Ad Hoc Manuscript Peer-Reviewer (refereed journals)**</u>

European Journal of Sport Science (2015)

ACADEMIC SERVICE

<u>**System**</u>

Poster Judge, UW-System Symposium for Undergraduate Research and Creative Activity, Office of Undergraduate Research, *University of Wisconsin-System* (Spring 2014)

<u>**College**</u>

Dean of the College of Health Sciences Search and Screen Committee, College of Health Sciences, *University of Wisconsin-Milwaukee* (Spring 2015)

<u>**Department**</u>

Task Force Member, Integrative Human Performance in Masters of Science in Kinesiology, Department of Kinesiology, *University of Wisconsin-Milwaukee* (Spring 2012)

COMMUNITY SERVICE

<u>**Wisconsin Science Education Foundation**</u>

Scientific Process Judge, *Badger State Science & Engineering Fair (BSSEF)* (2015)

<u>**City of Milwaukee Fire Department (MFD)**</u>

Instructor, Peer Fitness Trainer (PFT) Continuing Education Workshops (2013 – present)

“Building an Integrated Firefighter Performance Team”
“Movement Assessment in the Firefighter”
“Resistance Training & Prescription Basics for the Firefighter”
“Body Composition Assessment Technique”
“Power Training Principles for the Firefighter”
“Combine Testing Methods”