AN INVESTIGATION OF PHYSICAL ACTIVITY AND CARDIORESPIRATORY FITNESS IN CAREER FIREFIGHTERS

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

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ABSTRACT

Firefighters are responsible for protecting citizens as well as the infrastructure of cities across the United States. In order to safely protect and perform on-duty tasks, firefighters must be capable of performing physiologically demanding skills. Emerging evidence has led to heightened concern for firefighters' increased obesity levels and decreased physical activity (PA). Formal exercise and PA research specific to firefighters is lacking. More specifically, there is a lack of literature using accelerometers to objectively measure PA. There is more evidence, however, to demonstrate firefighters have a high prevalence of obesity surpassing the general population. Not only are firefighters overweight and inactive, but also they are not aerobically fit to adequately perform their job-specific tasks.

Purpose: To examine the relationship of PA and obesity to cardiorespiratory fitness (CRF).

Methods: Firefighters (n=29) wore an accelerometer for eight consecutive on- and off-duty days. The accelerometer was worn on the right hip and tracked sedentary activity, light physical activity (LPA), moderate physical activity (MPA), vigorous physical activity (VPA), and moderate-to-vigorous physical activity (MPVA). Additionally, each participant completed a stage-graded exercise test with submaximal square-wave verification bout to determine maximal oxygen uptake (VO_{2max}). A stepwise linear regression model was conducted using physical activity intensity, body mass index (BMI), and waist circumference (WC) as predictor variables for CRF.

Results: According to the World Health Organization BMI categorization, none were normal weight, 20 were overweight, and 9 were obese. Firefighters spent roughly 61% of their waking hours in sedentary activity, 35.4% in LPA, and only 3.6% in MVPA. The two linear regression models were used to investigate whether PA intensity, step count, physical activity

rating scale, BMI, or WC were more predictive of VO_{2max}. VPA was predictive of VO_{2max} ($F(1,27) = 7.89$, $R^2 = 0.23$, $p < 0.01$). Additionally, when BMI and WC were added, only WC was predictive of VO_{2max} ($F(1,27) = 11.76$, $R^2 = 0.30$, $p < 0.01$).

Conclusion: It is imperative fire departments emphasize the importance of cultivating an environment where improved health and wellness is essential for firefighters to adequately perform their physiologically demanding tasks.

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CHAPTER 1. INTRODUCTION

1.1. Overview of the Problem

In the United States, there is a growing concern for the economic and health care crisis that has resulted from the rise in obesity (Cawley & Meyerhoefer, 2012; Church et al., 2011; Finkelstein, Trogdon, Cohen, & Dietz, 2009; Lavie, Milani, & Ventura, 2009). In the past four decades, the prevalence in classifying adults as overweight or obese has shifted from fewer than 25% to nearly 70% (Flegal, Carrol, Ogden, & Curtin, 2010; Kuczmarski, Flegal, Campbell, & Johnson 1994; Ogden, Carrol, Fryar, & Flegal, 2015). One of the detrimental effects of obesity is the increased risk of all-cause mortality (Flegal, Kit, Orpana, & Graubard, 2013). After several decades of research, however, multiple causes have been linked to obesity (Walley, Asher, & Froguel, 2009). Thus, researchers are continually exploring ways to decrease obesity levels to improve overall health.

Physical activity is one modifiable lifestyle behavior that has been identified to decrease obesity and negative health outcomes. Large, prospective, primary prevention studies concluded active men were less likely to have coronary heart disease, hypertension, and all-cause mortality than their less active counterparts (Paffenbarger, Wing, & Hyde, 1978; Paffenbarger, Wing, Hyde, & Jung, 1983; Paffenbarger, Hyde, Wing, & Hsieh, 1986). Although negative health outcomes could be mitigated by physical activity, only 1 in 20 Americans are meeting the American College of Sports Medicine's physical activity guidelines (Troiano et al., 2008).

Emerging evidence has led to an increased concern for firefighters' increased obesity levels and decreased physical activity (Clark, Rene, Theurer, & Marshall, 2002; Durand et al., 2011; Poston et al., 2011). Formal exercise and physical activity research specific to firefighters is lacking. More specifically, there is a lack of literature using accelerometers to measure physical activity. There is more evidence, however, to demonstrate firefighters have a high prevalence of obesity that surpasses the general population (Poston et al, 2011). Firefighters, as well as the general public, are at risk for negative health outcomes because researchers have not formally investigated the many physiological facets of job-specific tasks.

1.2. Statement of Purpose

The primary purpose of this study was to understand associations for physical activity levels and obesity on cardiorespiratory fitness (CRF). The secondary purpose of this study was to investigate how physical activity differentiates between on- and off-duty days.

1.3. Research Questions

1. Do physical activity intensity levels, body mass index, and/or waist circumference predict cardiorespiratory fitness in career firefighters?
2. How do physical activity intensities differ between on- and off-duty days in career firefighters?

1.4. Dependent Variables

The dependent variable was CRF.

1.5. Independent Variables

The independent variables was the objectively measured physical activity via an accelerometer as well as anthropometric measures such as: height, weight, body mass index, and waist circumference.

1.6. Limitations

This was a multi-faceted study that was not without limitations due to the numerous variables involved. First, the participants in this study were employed by one fire department; thus, the results may not be generalizable to other regions. Second, the accelerometer can only track ambulatory activities, which can possibly lead to underestimation of physical activity for participants who engage in non-ambulatory activities such as swimming and cycling.

Additionally, there was no objective measurement for resistance training as the accelerometer is not a pattern recognition device to detect those specific movements.

1.7. Delimitations

This study used the ActiGraph GT3X+ accelerometer, which was unable to track certain activities such as cycling and weight lifting. Additionally, we used the Parvo metabolic cart instead of a portable metabolic cart. Finally, the firefighters performed a graded exercise test following the Balke-Ware protocol (Balke & Ware, 1959). Previous studies have utilized the Bruce protocol when investigating VO_{2max}. However, this study used Balke-Ware to simulate a job-specific task of ascending stairs.

1.8. Assumptions

There were a few assumptions made throughout the study. Since participants wore an accelerometer to monitor their physical activity levels throughout the day, it was assumed they engage in their typical daily routine. It was also assumed participants honestly reported their physical activity levels on the International Physical Activity Questionnaire. Additionally, it is assumed that participants truly participated until volitional fatigue on their cardiorespiratory fitness test. The square-wave verification test examined if participants truly did reach their volitional fatigue. Finally, it was assumed participants honestly reported their demographic information.

1.9. Significance of Study

Currently, research has only examined subjectively measured physical activity levels in firefighters. This was the first study to use objectively measured physical activity levels during on- and off- duty days in firefighters. Additionally, there was an association between objectively measured physical activity and the use of cardiorespiratory fitness test specific to firefighters. The results of this study suggest there is a need to improve physical activity and cardiorespiratory fitness in firefighters in order to reduce the occurrences of a cardiovascular event and improve overall health.

1.10. Definitions

Accelerometer is a device that measures acceleration from body movement, which can them be converted into intensity of physical activity (Chen & Bassett, 2005).

Cardiorespiratory fitness (CRF) is the cardiopulmonary system ability to adequately deliver oxygen to the muscles during bouts of physical activity typically measured in ml/kg/min (Lee, Artero, Sui, & Blair, 2010).

Exercise is a subcomponent of physical activity that is structured or planned to promote an increase in overall health (Caspersen, Powell, & Christenson, 1985).

Graded exercise test (GXT) is a screening tool used to assess the functional capacity of the cardiopulmonary system (Beltz et al., 2016).

High-quality CPR is an individual's ability to accurately perform compression rate (100-120 per minute), compression depth (at least 5.0 cm) and chest compression factions (Field et al., 2010).

Maximal oxygen consumption (VO_{2max}) is the peak oxygen uptake measured in ml/kg/min during a GXT (Bassett et al., 2001).

Parvo metabolic cart (ParvoMedics, Sandy, UT) uses a mixing chamber to analyze inspiratory and expiratory gas exchange to assess cardiorespiratory fitness (Bassett et al., 2001).

Physical Activity (PA) is any body movement that expends energy (Caspersen et al., 1985).

QCPR Resusci Anne (Laerdal,) is an adult training manikin that provides feedback to improve an individual's competency to perform high-quality CPR (Laerdal, 2017).

CHAPTER 2. LITERATURE REVIEW

Firefighters engage in physically demanding tasks in hazardous occupational environments (NIOSH Alert, 2007). Fitness levels in firefighters are an important consideration for ensuring they are capable of performing job-specific tasks. The National Fire Protection Association (NFPA) has implemented three codes to ensure the health and safety of firefighters by suggesting medical screenings and fitness-for-duty evaluations (NIOSH Alert, 2007). Specifically, code 1582 suggests firefighters maintain a cardiorespiratory fitness (CRF) level of at least 42 ml/kg/min to adequately and safely perform fire suppression tasks (NFPA, 2007). Although there is an increased emphasis on fitness, it has been reported firefighters are not maintaining the suggested CRF level (Baur, Christophi, Cook, & Kales, 2012; Elsner & Kolkhorst, 2008; Donovan et al., 2009; Durand et al., 2011).

The increased prevalence of obesity and decreased physical activity (PA) levels are contributing factors to decreased CRF levels. Obesity is a multi-dimensional disease that results in excess weight which negatively affects CRF. About 75% of firefighters are classified as overweight or obese with approximately 20% meeting the American College of Sports Medicine’s PA guidelines of 150 minutes of moderate intensity PA per week (Baur et., 2012; Clark et al., 2002; Durand et al., 2011; Poston et al., 2011; Soteriades et al., 2008; Tsismenakis et al., 2009). Researchers have concluded firefighters classified as normal weight and meeting the PA guidelines were more likely to meet the NFPA’s CRF standard compared to those firefighters who are classified as overweight or obese (Baur et al., 2012; Durand et al., 2011).

Although the number of medical calls is roughly 21,500,000 compared to only 1,300,000 fire calls a year, there is no literature investigating the minimum CRF level for firefighters to adequately perform life saving techniques such as cardiopulmonary resuscitation (CPR) after engaging in physical activity in order to reach a patient (NFPA, 2015). According to the Morbid

Mortality Weekly Report (CDC, 2009), there are roughly 460,000 sudden cardiac deaths each year in the United States. Thus, it is imperative that firefighters are appropriately prepared to perform high-quality CPR.

2.1. Obesity

The alarming prevalence of obesity in the United States had led to an economic and health care crisis (Cawley & Meyerhoefer, 2012; Church et al., 2011; Finkelstein et al., 2009; Lavie, Milani, & Ventura, 2009). In the past four decades, the prevalence in classifying adults as overweight or obese has shifted from fewer than 25% to nearly 70% (Flegal et al., 2010; Kuczmarski, Flegal, Campbell, & Johnson, 1994; Ogden et al., 2015). Obesity is a multi-dimensional disorder that is influenced by several interacting genetic and non-genetic factors. Initially researchers, health care professionals, and public health workers described obesity simply as an unbalanced equilibrium of calories consumed versus calories expended (Cutler, Glaeser, & Shapiro, 2012). After several decades of research, multiple causes have been linked to obesity (Han, Lawlor, & Kimm, 2010; Walley et al., 2009). Researchers have examined factors associated with the increase in obesity levels from infancy through adulthood, such as genetic, environmental considerations, and modifiable lifestyle factors.

2.1.1. Causes of Obesity

2.1.1.1. Environment

One of the causes of obesity is the imbalance of caloric expenditure resulting in over consumption of food and physical inactivity. Physical inactivity has been identified as the fourth leading cause of death (WHO, 2012). Over the past five decades, the increased use of automobiles and new technology has led to more sedentary lifestyles, which has emphasized the importance of examining environmental factors effects on obesity (Committee on Physical Activity, Health, Transportation, and Land Use, 2005). Various studies have explored the importance of environmental factors: the built environment (e.g., walkability, parks, buildings, and safety in neighborhoods), cost of food, availability food outlets (e.g., restaurants and grocery stores), technology, and modifiable behaviors.

2.1.1.2. Built Environment

Even though investigation of the built environment is still a relatively novel idea for preventing obesity, research is being conducted on the design of communities to promote greater physical activity (PA) (CDC, 2014; Doyle et al., 2006; Frank et al., 2003). As of 2009, 43% of all vehicle trips are for distances of three miles or less (FHA, 2009). The opportunity to substitute traveling by car for walking or bicycling could lead to an increase in PA. The Centers for Disease Control and Prevention's (CDC) Built Environment and Health Initiative is working to enhance the overall health of people by: "improving community design, educating policy makers on the health effect of community design, developing relationships between the policy makers and their influencers, conducting research to explore the best layouts for urban areas, and how to translate the research into the best practices" (CDC, 2014). Obesity rates have been suggested to decline if cities became proactive and integrated these initiatives into their frameworks.

Although these concepts seem logical, there are specific frameworks that are more conducive for promoting PA (Bauman et al., 2012; Brennan et al, 2006; Cho et al., 2009; Hoehner et al., 2005; McGinn et al., 2007; Sallis et al., 2016). One of the main focuses for encouraging PA in the built environment is transportation (Andrews, Hall, Evans, & Colls, 2012; Bauman et al., 2012; Brennan et al., 2012). More specifically, extensive research has investigated the influence of a community's walkability. Walkability is the measure of how easily a person can walk in a given built environment (Andrews et al, 2012). Residents who live in communities that are densely populated have access to interconnected streets and are in close proximity to shops, services, public transport, restaurants, and parks in locations with increased walkability (Bauman et al., 2012; Heath et al., 2006). The safety of the neighborhood also plays a vital role in the walkability. People who live in close proximity to services are more physically active than their counterparts who reside in less walkable areas (Bauman et al., 2012; Heath et al., 2006).

An extensive analysis from the International Physical Activity and Environment Network (IPEN) sampled varying levels of walkability and socioeconomic status across 14 cities in ten countries and across five continents, including the United States (Sallis et al., 2016). The results revealed four environmental attributes that were positively correlated with PA: net residential density (p=0.001), intersection density (p=0.019), public transportation density (p=0.0007), and the number of parks (p=0.010). Net residential density is the number of houses and apartments on residential land with a certain radial distance. Intersection density is the number of street intersections that are easily accessible by pedestrians divided by a given amount of land. Public transit density is the number of public transportation stations divided by a given amount of land (Sallis et al., 2016, p. 2210). After identifying four main environmental attributes that promote increased PA levels, studies can use this as a catalyst to enhance the future of built environment research.

2.1.1.3. Technology

Technology also plays a role in the ever-changing physical, economic, and social environments around the world. Many of the technological advancements include: transportation, communication, domestic work and entertainment, and market work, which directly affect the levels of obesity transitioning from active to sedentary activities (Owen et al., 2012). The technological upgrades have reduced the EE from activities of daily living (ADL). The reduction in energy expenditure (EE) in ADLs has increased the need for formal exercise within an individual's day (Lakdawalla et al., 2009). Consequently, the cost of PA has increased while the cost of calories has declined (Lakdawalla et al., 2009; Christian & Rashad, 2009).

The advancements in technology have diminished not only the EE, but also the time needed for food production (Lakdawalla et al., 2009). Large machinery has lessened the need for manual labor jobs in the agriculture industry. Additionally, the new machines have increased the efficiency of food production. The technological enhancements have allowed for reallocation of time from food production to the manufacturing of other goods and services (Lakdawalla et al., 2009). This transition has prompted the price of PA to increase. American workers are no longer being paid to be active on the job. Thus, there is an increase in payment of leisure-time activities such as going to the gym or playing for a recreational club team (Lakdawalla et al., 2009).

2.1.1.4. Modifiable Lifestyles

Large, population-based studies have depicted a bleak future for sedentary behavior in U.S. adults (Healy et al., 2011; Matthews et al., 2008; Matthews et al., 2012). Adults spend the majority of time in their waking hours in sedentary pursuits in both domestic and work environments. The increase in time spent participating in sedentary activities can induce a caloric imbalance causing an increase in weight. More emphasis needs to be placed on reduction in screen time not only in children but also in adults to decrease sedentary behavior.

People spend the majority of their day, roughly eight hours, at work; however, until recently, researchers had not examined the decline in occupational PA, nor its association with the rise in obesity (Church et al., 2011). Church et al. (2011) used nationally representative data to assess the prevalence of goods producing (mining-logging, construction, manufacturing), service providing (trade, finance, education, health, etc.), and agricultural occupations. In order to determine mean occupational-related metabolic equivalents (MET), the researchers used the corresponding activities from the PA Compendium to assign the MET value to each activity

(Tudor-Locke, Ainsworth, Washington, & Troiano, 2011). The PA Compendium is a database that has been developed to allow researchers to assign MET values to variety of activities including: leisure, occupational, and exercise. Additionally, a previously validated energy balance differential equation model was used for weight change. The model was then compared to the NHANES data for the past 50 years. The results revealed that in the 1960s, over half of the private industry occupations in the U.S. required at least moderate intensity PA compared to less than 20% in 2010 (Church et al., 2011). It was estimated the reduction in moderate intensity PA consequently resulted in a decrease of 100 calories expended for both men and women. Thus, a decrease in roughly 500 calories expended in a typical five-day workweek contributes to the rise in obesity. The researchers noted the loss in calories expended could have been adequately compensated if individuals adhered to the American College of Sports Medicine's PA recommendations of 150 minute of moderate intensity PA per week.

Adults spend the majority of their waking hours in an occupational environment; therefore, occupational PA has a significant effect on total caloric expenditure (Church et al., 2011). There needs to be more emphasis in reducing screen time, which in turn could reduce sedentary behavior, especially in a work environment. More joint collaborations between public health officials, policy-makers, practitioners, and researchers are required to mitigate sedentary behavior.

2.1.2. Measurements of Obesity

There are several measurements that can be used to classify adults as overweight or obese. In the discipline of physiology, body fat mass and absolute or relative body fat percent are used to classify people as overweight or obese using dual-energy x-ray absorptiometry (DEXA), bioelectrical impedance analysis (BIA), hydrostatic weighing, and air displacement plethysmograph (Hebert, Allison, Archer, Lavie, & Blair, 2013; Rothman, 2008). In epidemiological research and medicine, body mass index (BMI), waist-to-hip ratio, and waist circumference (WC) are used to classify people as overweight or obese (Hebert et al., 2013). These measurements are used to directly or indirectly assess the amount of body fat within an individual. The most common measurement in epidemiological and medical research is BMI (Herbert et al., 2013).

The simplicity of BMI allows researchers and medical professionals to use this noninvasive measure without increasing the burden on the participant or patient. BMI is a tool which measures an individual's weight in relation to their height (kg/m^2) (Shields, Gorber, & Tremblay, 2008). The World Health Organization (WHO) has six classifications of BMI for adults: underweight (<18.5), normal weight (18.5 - ≤ 24.9), overweight (25.0 - ≤ 29.9), obese class I (30.0 - ≤ 34.9), obese class II (35.0 - ≤ 34.9), and obese class III (≥ 40.0) (WHO, 1995). This objective measure can be used quickly to classify individuals' weight status.

Although BMI is a basic measure, there are some issues to consider. First, it is an indirect measure of body fat, so percent changes of fat and muscle mass cannot be detected (Rothman, 2008). Second, in some research, BMI is calculated from convenient, self-reported data. Studies have reported participants typically underestimate their weight and overestimate their height (Nawaz et al., 2001; Nyholm et al., 2007). Therefore, researchers should use BMI when examining body weight and measure height and weight instead of relying on self-reported measures from participants.

Additionally, research has shown the importance of measuring WC in conjunction with BMI to more accurately classify individuals as overweight or obese (Katzmarzyk, Hu, Cefalu, Mire, & Bouchard, 2013; Cahmi et al., 2011). WC and BMI have been shown to have similar correlation with subcutaneous fat (r= 0.82-0.92 and r= 0.86-0.93, respectively) and fat mass (r=

0.85-0.93 and *r*= 0.91-0.94, respectively) when adiposity was compared to DEXA or CT scans (Cahmi et al., 2011). There was a difference, however, in the correlation of visceral fat mass for WC (*r*= 0.73-0.77) and BMI (*r*= 0.61-0.69) (Cahmi et al., 2011). These results indicate the need for both measurements when trying to predict multiple components of fat mass. Further, associations have shown WC (HR: 1.40, 95% CI: 1.14-1.72) and BMI (HR: 1.29, 95% CI: 1.04-1.61) are independent predictors of all-cause mortality (Katzmarzyk et al., 2013). Thus, researchers should use both measurements to predict fat mass to classify individuals as overweight or obese.

2.1.3. Obesity Paradox

In the past 15 years, there has been emerging evidence of an ‘obesity paradox’ (Lavie, 2016 et al.). Gruberg and colleagues (2002) were the first to coin this phenomenon when investigating the effects of BMI on short- and long-term outcomes following percutaneous coronary intervention (i.e., angioplasty with a stent). The obesity paradox suggests people who are categorized by BMI as overweight or obese (class I) and diagnosed with cardiovascular diseases (CVD) have a better prognosis than their leaner counter parts (Lavie et al., 2009). These noteworthy results demonstrated that patients with known coronary artery disease who had a BMI <25 were at the highest risk of in-hospital complications and cardiac death as opposed to overweight and obese (class I) individuals who had better patient outcomes (Lavie et al., 2009; Lavie et al., 2011; Lavie et al., 2012; Lavie et al., 2013; Oreopoulus et al., 2008; Voulgari et al., 2011). Similar results have been reported when investigating other measures of adiposity including percent body fat (%BF) and waist circumference (Clark et al., 2002; Lavie et al., 2003; Lavie et al., 2009; Lavie et al., 2011; Lavie et al., 2012). Contrary to popular belief, this research demonstrates some additional fat may be protective against negative health outcomes.

The effect of CRF on the obesity paradox is a relatively new concept. A recent study with 10,000 CHD patients demonstrated the obesity paradox was present in the lower third of fitness but not in the upper two-thirds (McAuley et al., 2012). The results suggested that CHD patients who were classified as overweight according to BMI (HR: 1.09, CI 0.88-1.36), %BF (HR: 1.28, CI: 0.99-1.67) and WC (HR: 1.05, CI: 0.81-1.37) with lower fitness levels have a similar prognosis to leaner, fit patients. A similar study, however, resulted in conflicting data suggesting a good prognosis in CHD patients with low fitness regardless of adiposity status (Goel et al., 2011). Thus, further research needs to be conducted to understand the effect of CRF on the obesity paradox for individuals with coronary heart disease (CHD).

In the past two decades, there has been emerging evidence reporting the independent effects of CRF and obesity on mortality (Kodama et al., 2009). The independent effects of these variables has led to the fitness-fatness hypothesis, which suggests individuals who are overweight or obese but also fit are no longer at increased risk for mortality compared to their normal weight fit peers (McAuley et al., 2011). There is substantial evidence to support the association between CRF and fatness on mortality; however, there is overwhelming evidence supporting CRF is far more important than fatness as a mortality risk factor (Blair et al., 1989; Church, LaMonte, Barlow, & Blair, 2005; McAuley et al., 2009; Stevens et al., 2002; Stevens et al., 2004; Sui et al., 2007).

A recent meta-analysis investigated the effect of unfit and fit individuals across normal, overweight, and obese BMI statuses on mortality (Barry et al., 2014). After pooling the hazard ratios from 10 articles, the results demonstrated unfit individuals, regardless of BMI status, doubled the risk of mortality compared to normal weight fit individuals. Furthermore, individuals who were classified as overweight- and obese-fit had similar morality risks as normal weight-fit individuals; thus, overweight- and obese-fit individuals may have better health outcomes compared to normal weight unfit individuals.

2.1.4. Obesity Conclusion

Researchers and health professionals should continue to collaborate to understand and potentially mitigate the links between these factors and obesity. Although the obesity epidemic is causing a health care crisis, it is important to note some extra adipose tissue might serve as a potential benefit for decreasing all-cause mortality and CHD/CVD events. Even though there are numerous variables linked with an increase in obesity, this paper will primarily focus on the physical activity (PA) aspect of modifiable behaviors.

2.2. Physical Activity

2.2.1. Physical Activity History

Modifiable lifestyle behaviors have been identified as key factors to alter negative health outcomes. Modifiable lifestyle behaviors, such as reduced screen time, improved dietary choices, and increased physical activity, can directly influence obesity. In this paper, the primary focus will be the influence of increased PA to avoid the detrimental health outcomes from physical inactivity.

First, it is important to distinguish the difference between exercise and PA. Some authors define PA as any body movement that expends energy (Caspersen et al., 1985, p.126); whereas, exercise is a subcomponent of physical activity that is structured or planned to promote an increase in overall health (Caspersen et al., 1985). Group exercise classes, going to a workout facility, and playing on an organized sport team are some examples that would be considered exercise rather than PA. Unfortunately, not all researchers clearly differentiate between the two terms. For the purpose of this paper, exercise and PA will be used interchangeably due to the lack of clear definitions used across publications.

Two prominent epidemiological researchers have been credited with revealing the effects of PA on reducing non-communicable diseases. As certain non-communicable diseases, e.g., CHD, were on the rise in the early to mid-1900s, researchers were prompted to find a cure for CHD (Paffenbarger et al., 2001). Since as early as the 1940's, researchers have studied the effects of inactivity on CHD. For example, Morris et al (1953) showed transportation conductors were less likely to have a heart attack than their less active counter parts, double-decker bus drivers. More specifically, the rate of CHD death in conductors and drivers were 1.9 per 1,000 and 2.7 per 1,000, respectively. A similar study comparing civil service executives and clerks who sat at their jobs compared to postmen who were expected to walk their mail routes had similar results (Morris, 1953). The incidence rate for CHD was larger in executives and clerks (2.4 per 1,000) than postmen (1.8 per 1,000). A larger, prospective, primary prevention study concluded the same results where more active men were less likely to have CHD, hypertension, and all-cause mortality than their less active counterparts (Paffenbarger et al., 1978; Paffenbarger et al., 1983; Paffenbarger et al., 1986). These initial studies developed the framework for future researchers to investigate further the relevance of PA on non-communicable diseases.

Dr. Paffenbarger's research was the first to incorporate survey data to investigate the effects of activities of daily living (ADL) and the duration and type of sport participants engaged to prevent non-communicable diseases. The PA index was developed to account for the total amount of energy expended, denoted in kcals, individuals completed during ADLs and formal exercise. Men who expended 2000-2999 kcals per week had the least number of heart attacks compared to men who had a lower PA index. Men who climbed less than five flights of stairs per day were 1.25 times more likely to have a heart attack than men who climbed more than five flights per day (Paffenbarger et al., 1978). Additionally, men who did not participate in strenuous sports (e.g., basketball and running) were 1.41 times more likely to have a heart attack than those who engaged in strenuous sports. This initial study served as a catalyst to further investigate the effects of ADL and sport on additional non-communicable diseases.

By the mid- to late-1980s, epidemiological studies incorporated CRF as well as occupational and leisure time activities as measures of PA (Blair, LaMonte, & Nichaman, 2004). The sole use of self-reported activity data made it difficult to capture the precise amount, type, and intensity to determine the recommended level of PA. The addition of CRF allowed researchers to have an objective measure of PA behaviors, which established a stronger relationship between increased PA and reduced health outcomes (Blair et al., 1989; Erikssen et al., 1998; Ekelund et al., 1988). Even though objective data was supplemented to epidemiological research, there was no way to identify the duration, time, type, and intensity of exercise to reduce negative health outcomes.

Shortly after the first epidemiological studies examined the effects of PA on non-communicable diseases, exercise training studies started to investigate the frequency, intensity, time, and type of exercise needed in order to augment the positive effects of exercise on certain diseases (Blair et al., 2004). Karnoven et al (1957) conducted the first exercise training study to investigate the differences in exercise heart rate between two different intensities for males (n=6) ages 20-23. Participants engaged in 30 minutes of treadmill running at varying intensities for four or five days per week for four consecutive weeks. It was concluded that participants who trained at ≥60% of their heart rate reserve were able to increase their aerobic work capacity. (Karnoven, Kentala, & Mustala, 1957). Thus, this study initiated the investigation on quality and quantity of exercise to enhance CRF.

2.2.2. History of ACSM Guidelines

As exercise training further developed, more emphasis was focused on determining the minimal amount of exercise to improve CRF (ACSM Position Stand, 1978). Manipulation of frequency, intensity, and duration was used to investigate the improvements on $VO_{2maximum\ (max)}$. Frequency was typically measured by alternating between one to five days per week of exercise (Crews & Roberts, 1971; Davies & Knibbs, 1971, Pollock, Cureton, & Greninger, 1969). Two different modalities, heart rate and percent VO_{2max}, were used to asses intensity of the exercise (Crews & Roberts, 1971; Davies and Knibbs, 1971; Davis & Convertino, 1975; Karnoven et al., 1957). Duration was measured in minutes per day, which fluctuated between 15 to 90 minutes (Davies Roberts, 1971; Gwinup, 1975; Misner et al., 1974). An accumulation of studies examining frequency, intensity, and duration enhanced the need for general guidelines for Americans to follow to promote increased CRF.

Decades after Karnoven and colleagues published their results, the American College of Medicine (ACSM) was the first organization to clearly define exercise guidelines for the lay public. The 1978 guidelines suggested that the healthy adults who are interested in improving or maintaining CRF should engage in three to five days per week with 15-60 minutes of continuous aerobic exercise per day (Pollock, 1978). More specifically, individuals should reach 60-90% of heart rate max or 50-80% of VO_{2max} and incorporate exercises that focus on large muscle groups (Pollock et al., 1978). The ACSM guidelines in 1978, 1990, and 1998 predominately focused on formal exercise instead of PA. The guidelines were presented as frequency, duration, and intensity (percent of heart rate reserve [HRR], heart rate maximum [HRmax], and percent of VO_{2max}). The lay public was unable to conceptualize the physiologic measures presented by the ACSM, which made the guidelines less transparent. As a result, the general American population did not know how to interpret these guidelines causing a lack of increased activity levels.

Based on the lack of transparent guidelines, a joint collaboration between the Centers for Disease Control and Prevention (CDC) and ACSM established guidelines that could be utilized by the majority of Americans. The recommendation suggested every adult should accumulate at least 30 minutes of moderate-intensity PA on most days of the week (Pate et al., 1995). These recommendations began the paradigm shift from solely focusing on formal exercise to an inclusion of PA. The main interest of the new recommendations was to focus on the public health perspective where at least 30 minutes of PA could limit overall health problems such as CHD. Today, the 2008 physical activity guidelines are now the public health recommendation with "150 minutes of moderate-activity or 75 minutes of vigorous-activity per week" (2008 guidelines).

Because there is a difference in terminology between PA and exercise, it is important to note there are specific recommendations for exercise. In 2011, the ACSM published a recommendations update for exercise prescription. The guidelines include resistance, flexibility, and neuromotor exercises (e.g., balance, agility, coordination, gait) in addition to the cardiorespiratory considerations (Garber et al., 2011). The additional recommendations to emphasize individualized exercise prescriptions that focus on strength, range of motion, motor skills in addition to CRF to further improve overall health in U.S. adults (Garber et al., 2011). It is imperative to continue to provide scientific evidence to develop detailed PA and exercise guidelines to prevent non-communicable diseases within the US adult population.

2.2.3. Association between Physical Activity and Cardiorespiratory Fitness

Physical activity is positively correlated to CRF; individuals who engage in PA will improve their CRF levels (Kulinski et al., 2014; Lakoski et al., 2011; Stofan et al., 1998). A cohort design study with 2,223 participants who engaged in a CRF test and wore an accelerometer for seven consecutive days demonstrated the importance of PA and sedentary behavior on CRF. For each additional hour of moderate-to-vigorous physical activity (MVPA) men participated, there was an 0.88 MET increase in fitness. On the other hand, for each hour of sedentary activity, the MET fitness value declined by 0.12. Thus, if an individual sits for roughly 8 hours a day, it could negate the benefit of one hour of MVPA.

Lakoski and colleagues (2011) investigated clinical modifiable and nonmodifiable determinates of CRF. Four clinical variables were categorized into modifiable (PA and BMI) and nonmodifiable (age and gender) determinants. The participants engaged in a VO_{2max} test while PA was assessed by a self-reported questionnaire. The frequency and duration from the PA questionnaire were then converted into METs per minute per week using the physical activity compendium (Ainsworth et al., 2000). The participants were divided into four PA groups: 1) 0 METs/min/wk, 2) 1-499 METs/min/wk, 3) 500-749 METs/min/wk, and 4)≥ 750 METs/min/wk. After performing a linear regression, the combination of the four clinical variables explained 56% of the variance of CRF (Lakoski et al., 2011). The addition of other clinical factors such as smoking, blood pressure, cholesterol and health status only increased R-squared by 2%. Again, the results indicate the importance of PA when trying to improve CRF.

2.2.4. Measurement of Physical Activity

2.2.4.1. Overview of Accelerometers

Researchers developed accelerometers to gather objectively measured physical activity output. The primary aim of the accelerometer is to utilize acceleration to measure different movement patterns to estimate the amount of PA over time (Chen & Bassett, 2005). The use of accelerometers has increased over the past two decades, which has increased the number of accelerometers available for researchers (Kelly, 2013). Acceleration is a change in speed with respect to time and is usually measured in gravitational units of (9.8 $m \bullet s^{-2}$) (Chen & Bassett, 2005). As the human body produces acceleration, the accelerometer is able to capture and quantify various intensities (Chen & Bassett, 2005).

The GT3X is one of the most common accelerometers and has become one of the standard units within PA epidemiology research (Jarett, Fitzgerald, & Routen, 2015, Saski, John, & Freedson, 2011). The small (3.8 cm x 2.7 cm x 1.9 cm), compact, plastic device weighs 27 grams. The GT3X measures acceleration in three orthogonal planes: vertical, anterior-posterior, and medio-lateral. The capability to capture acceleration in these three planes classifies the GT3X as triaxial.

The raw output from accelerometers provides counts to measure the intensity of PA. The numerical value of the raw count is determined from the voltage signal. To make these raw values into a usable variable, one of the most common approaches is to use an algorithm that can determine the minimum and maximum value for a selected time period (epoch). Using the raw data allows researchers to examine specific time points to better understand participants' PA patterns.

2.2.4.2. Methodological Considerations for GT3X

2.2.4.2.1. Epoch Duration

Determining the epoch length is a critical part of the research methodology because the time frame will allow researchers to evaluate PA patterns within a specific sample population. An epoch is a user-defined time interval for which the accelerometer can summarize the data (Heil, Brage, & Rothney, 2012). The epoch is closely related to PA outcome variables; thus, determining the epoch length should be decided before the start of a study. Traditionally, a 60-second epoch length has been used because it reflects the same duration for which indirect calorimetry measures steady-state oxygen consumption (Heil et al., 2012).

Additionally, calibration studies typically use the 60-second epoch to form a relationship between the monitor and energy expenditure that is measured from the indirect calorimeter. Another factor to consider when selecting epoch length is the cutpoint algorithm which will be used to convert the raw data into meaningful measures of PA intensity levels. The algorithms have been validated using a specific epoch length. When examining PA in adults, the majority of algorithms use 60-second epochs because adults have few sporadic changes in activity levels. Adults typically perform activities for durations of at least 60 seconds if not longer (Freedson, Melanson, & Sirard, 1998). Thus, determining the epoch length is a crucial part of the study as it is a vital part of determining the PA intensity.

2.2.4.2.2. Location of Monitor

Researchers must consider what PA they want to capture when determining where the monitor should be worn. The GT3X can be worn on the wrist, hip, thigh, ankle, and chest, but the most common locations are the hip and wrist (Kamada, Shiroma, Harris, & Lee, 2016; Ozemek et al., 2014; Zhang, Macfarlane, & Sobko, 2016). The hip allows the monitor to measure accelerations near the body's center-of-mass, which can accrue more movement patterns. Moreover, the first validation studies conducted on uniaxial accelerometers used the hip location during the validation process (Troiano et al., 2014). Larger epidemiological studies adopted the hip location for the accelerometer to be worn causing other studies to replicate the same methodology.

Few studies have examined the differences between placing the monitor on the right or left hip. Jarret and colleague (2015) had participants wear two monitors concurrently on bilateral hips for a 24-hour period. A paired t-test revealed there was no significant difference between the two locations for assessing PA intensities (p>0.05) (Table 1). A similar study had participants wear two monitors simultaneously on their right and left hip for one-, seven-, and 21-day periods

(Aadland & Ylvisaker, 2015). A linear mixed model regression concluded no significant difference between the contralateral hips for PA intensities (Table 2). It has been suggested that in order to keep studies uniform to compare results, the monitor should be worn on the right hip (Aadland & Ylvisaker, 2015).

Table 1

PA intensities means ± standard deviations for GT3X+

PA Intensities (min)	Right Hip (mean ± SD)	Left Hip (mean ± SD)	Mean APD	Mean CV	ICC
<Moderate	732.30 ± 96.67	735.43 ± 98.77	2.09	1.48	0.97
Moderate	89.45 ± 33.54	87.86 ± 34.46	5.13	3.63	0.99
Vigorous	19.25 ± 12.19	18.54 ± 11.83	17.36	12.28	0.97
Very Vigorous	11.07 ± 11.63	11.03 ± 10.69	25.36	18.15	0.98
Moderate-to-Vigorous	119.78 ± 41.33	117.43 ± 41.36	4.05	2.85	0.99

Table 2

PA intensity differences between contralateral hips for GT3X

PA Intensities (min/day)	Difference	*p*	Effect Size
Sedentary	4.7	0.216	0.042
Light	1.2	0.513	0.016
Moderate	-0.2	0.858	0.005
Vigorous	-0.2	0.641	0.014
Moderate-to-Vigorous	-0.4	0.745	0.009

2.2.4.2.3. Valid Number of Hours

Researchers have two sampling frames to choose from when conducting PA epidemiological research (Matthews, Hagstromer, Pober, & Bowles, 2012). For the first sampling frame, the participant is required to wear the accelerometer for a 24-hour period, which includes all waking and sleeping hours. The second sampling frame occurs when the participant is asked to wear the accelerometer for a period lasting multiple days. The second sampling frame is most common for exploring PA behavior patterns. The multiple day approach not only includes a valid number of days but also a valid number of hours per day. In recent years, a consensus has emerged to use 10 hours per day as the standard valid day criteria (Matthews, Hagstromer, Pober, & Bowles, 2012).

2.2.4.2.4. Minimum Wear Days

The key for researchers is to find the balance between being able to capture an individual's typical PA habits and reducing the burden on the individual. A review investigated the minimum number of days needed for valid results, which suggested three to five days would be sufficient for monitoring PA patterns in adults (Trost, McIver, & Pate, 2005). More specifically, one study concluded three to four days would yield an interclass correlation coefficient (ICC) of 0.80, whereas a seven-day monitoring period had an ICC of 0.90 (Matthews, Ainsworth, Thompson, & Bassett, 2002). Researchers should consider implementing a minimum of a seven-day wear period to accurately monitor behavior changes which might occur between weekend and weekdays.

2.2.4.2.5. Nonwear Time

Nonwear time is the time the accelerometer is not worn. This could include sleeping and removing the accelerometer for specific reasons (e.g., showering or swimming) (Heil et al., 2012; Trost et al., 2005). Nonwear time can be detected through the use of algorithms or a log sheet for participants to document when the accelerometer was removed. There are two widely accepted nonwear time algorithms used in PA epidemiological research (Heil et al., 2012). The algorithms utilize the counts per minute (CPM), which is the raw data obtained from the different axes, specifically the vertical axis. If there was at least one CPM for the 60-epoch length, this would indicate there was some form of human movement. When there is a zero in the CPM, this could represent sedentary behavior or nonwear time. Thus, to accurately capture the amount of time spent in sedentary or PA, it is essential to properly account for nonwear time data.

In order to mitigate the burden of the data cleaning process, nonwear time algorithms were developed. Nonwear time, using Troiano's (2008) criteria, was classified as a 60-minute window with zero consecutive CPM with up to two minutes of sporadic nonzero counts less than or equal to 100 counts. The sporadic nonzero counts are movement artifacts, which were actions not directly caused by the individual. Troiano's algorithm has been used to detect and eliminate nonwear time data in large population-based studies such as the National Health and Examination Survey (Matthews et al., 2008).

Troiano's algorithm was validated in a laboratory environment by Choi and colleagues (2011). Participants were asked to wear the accelerometer for 24 hours in a whole-room indirect calorimeter while documenting a detailed record of any activities and episodes where the monitor was removed. During the evaluation process, researchers created another nonwear time algorithm. Choi's algorithm consisted of three different components with the first two being the same as Troiano's. First, the 60-minute window was extended to 90 minutes of consecutive zero counts. Second, the two minutes of sporadic nonzero counts eliminated the 0-100 count threshold. Finally, the new component investigated data for artifactual movement 30 minutes before and after the two minutes of sporadic nonzero counts. The new component was included to help reduce the likelihood of misclassifying the nonwear as wear time and account for artifactual movement detected at more time periods within the window.

After comparing the two algorithms, there was a difference in classifying activities at specific intensities. Troiano's algorithm incorrectly classified sedentary activities as nonwear time more often than Choi's. This means that Choi's algorithm is less likely to falsely classify time spent in sedentary behavior as nonwear time. For this reason, Choi's algorithm is better suited to assess the PA patterns in American populations where there is an increased prevalence of sedentary behavior.

2.2.4.2.6. Cutpoint Algorithms

The proper PA intensity cutpoint needs to be selected in order to accurately quantify and elucidate the dose response relationship between PA and positive health outcomes. There are several PA intensity cutpoint algorithms available; thus, it is essential to choose the most relevant one for the research being conducted (Crouter, Clowers, & Bassett, 2006; Crouter, Kuffel, Haas, Frongillo, & Bassett, 2010; Freedson et al., 1998; Hendelman et al., 2000; Matthews et al., 2005; Metzger et al., 2008; Sasaki et al., 2011; Swartz et al., 2000; Troiano et al., 2008; Yngve et al., 2003). Freedson (1998) was the first to develop a linear regression model that used the counts from the raw data to quantify the intensity of PA. The development of the multi-linear and non-linear models allows researchers to determine which algorithm to use based on the activity intensity, variation of movement, and the type of movement participants engage (Lyden, Kozey, Staudenmeyer, & Freedson, 2011). With more algorithms available, it is vital to select cutpoints based on specific intensities and type of movement being performed by participants to clearly capture the proper intensity of each activity.

2.2.4.3. Validity of Accelerometers

2.2.4.3.1. Research Laboratory

Initially, validation studies of GT3X accelerometers were conducted in a controlled environment such as a research laboratory (Calabro et al., 2014; Freehan et al., 2016; Kelly et al, 2013). The controlled environments have structured activity protocols using treadmills or specific activities; whereas, the free-living environments have very little structure but allow for typical human behavior. The utilization of a controlled environment enabled researchers to specifically target different modes of PA to capture a particular intensity.

The controlled environment requires the use of specific laboratory equipment to validate the newest model of accelerometers, the Actigraph GT3X. Most studies use one of two methods to validate the GT3X: indirect calorimetry, better known as volume of oxygen (VO_2), (Calabro et al., 2014; Freehan et al., 2016; Kelly et al, 2013;) and whole-room calorimetry (Choi et al, 2011) to predict energy expenditure. Indirect calorimetry using metabolic carts requires subjects to breathe room air through a mouth piece with their nose closed. The expired, mixed air is collected through the mouth piece then analyzed by gas-specific sensors. The expired gas is analyzed into VO_2 (O_2 consumed) and VCO_2 (CO_2 produced) in ml/min then converted into energy expenditure in kcal/day (de Rocha, Alves, & de Fronseca, 2006). Whole-room calorimetry is less invasive than indirect calorimetry because subjects are monitored in a research room which has the capability of gathering gas-specific data while a subject performs activities of daily living (ADL) rather than attached to a metabolic cart.

Validation studies examined the accuracy of the different PA intensities: sedentary, light, moderate, and vigorous. Validation is the process in which researchers check or prove the accuracy of a device. It is vital that accelerometers used in research are valid in detecting the intensity level to demonstrate the relationship between PA and negative health outcomes.

Feehan and colleagues (2016) examined the validity of GT3X and the SenseWear Mini (SWm) for assessing sedentary and light activities. Twenty-two subjects performed nine different activities of daily living for three minutes per activity. The nine activities were separated into three categories: standing (slow treadmill walking; washing, drying, and putting away dishes), sitting (slow stationary bike, light work station tasks, sitting motionless in a comfortable chair watching TV), and lying in the supine position (alternating knee range of motion over pillow, reading magazines, lying still listening to music). Participants were asked to perform each activity as they typically would under normal living conditions. Three sedentary cut-point criteria were applied: 1) the single vertical axis (VA) <100 activity counts (AC) per minute, 2) <25 AC/min, and 3) triaxial vector magnitude of <200 AC/min. Sensitivity was used to identify sedentary activities. All three GT3X cutpoints rarely misclassified light activity as sedentary with a sensitivity value of 0.99 and a false negative rate of 2%. The GT3X specificity values for correctly identifying light activity was .27 (VA < 100) to .47 (VM <200), whereas the SWm had a specificity ranging from 0.61-0.71. The results suggest that the GT3X is better at classifying sedentary activity compared to light activity.

Conversely, a main objective from Kelly el al (2013) was to determine whether the GT3X could be used to monitor light activity. This investigation explored the validity of the GT3X for identifying light-, moderate-, and vigorous-intensity activities compared to the results of a Parvo metabolic cart (ParvoMedics Inc., Sandy, UT). Forty-two adults exercised at three different speeds on a treadmill for six minutes at each intensity with a five-minute rest between each bout. Participants slowly walked (4.2 km/h), speed walked (6.4 km/h), and ran (9.7 km/h) in order to compare intensities. The overall correlation between activity counts/min for the GT3X related to VO_2 (ml/kg/min) for the Parvo metabolic cart was significantly correlated ($r=0.810$, $p<0.001$). Unlike previous studies, this study suggests the GT3X is a favorable monitor to use not only for detecting light-intensity, but also moderate- and vigorous-intensity activities.

A recent study investigated the validity of the GT3X for assessing activities at 1.5 (light), 3 (moderate), and 6 (vigorous) metabolic equivalents (METs) to examine its ability to capture various intensities (Powell, Carson, Dowd, & Donnelly, 2016). Fifty-six adults engaged in six different activities while wearing a portable metabolic cart. The activities included: lying in the prone position, sitting, standing, slow walking (2.5-4.5 km/h), brisk walking (4.5-6.5 km/h), and jogging (6.5-8.5 km/h). During the ambulatory activities, participants were able to select their speed within the respective range for each activity. Sensitivity was used to examine if the GT3X correctly identified points at or above the activity intensity thresholds whereas, specificity examined whether or not the monitor excluded activities below the activity intensity thresholds. The area under the curve (AUC) investigated if the monitor would correctly classify the activity. The values of AUC were: 1 represented perfect classification, greater than or equal to 0.9 was excellent, 0.80-0.89 good, 0.70-0.79 fair, and less than or equal to 0.70 poor. All analyses used the vertical axes to determine the number of counts from a 60 second epoch. The AUC, sensitivity, and specificity values for 1.5, 3, and 6 METs can be found in Table 3. Once again, the results demonstrate the ability of the AG GT3X to correctly identify light, moderate, and vigorous intensities.

Table 3

AUC, Sensitivity, and Specificity Values for GT3X

METs	AUC	Sensitivity	Specificity
1.5	0.926	0.866	0.909
3	0.991	0.942	0.944
6	0.997	0.962	0.963

2.2.4.3.2. Free-Living Environments

Accelerometers have also been validated in free-living environments as opposed to a static laboratory setting. It is equally important to validate accelerometers in a free-living environment for researchers to understand behavior patterns within different populations. This particular type of research allows investigators to observe PA behaviors in individuals' typical environment, which is crucial to understanding how PA can positively affect health outcomes.

A recent study investigated the differences in classifying activity intensities between the GT1M and the GT3X in free-living environments (Vanhelst et al., 2012). Both devices were worn concurrently for one typical weekday with an epoch of 60 seconds. The Freedson 1998 cutpoints were used for classifying different intensities were sedentary 0-99 counts/min, light 100-1951 counts/min, moderate 1952-5723 counts/min, and vigorous greater than or equal to 5724 counts per minute. The concordance correlation coefficient for sedentary, light, moderate, and vigorous intensities was 0.99. The mean difference for the number of minutes spent in each intensity ranged from 0.36-0.56, which was not significantly different ($p>0.05$). Therefore, the GT3X can be used in free-living environments to accurately assess PA behaviors across all intensities.

Reid-Larson et al (2012) not only investigated the validity of the GT3X in a free-living environment but also examined the effects the low frequency expansion (LFE) option for the GT3X. The LFE was designed to extend "…the lower end (baseband) of the filter cutoff to, effectively expanding the bandwidth frequency of the accumulated data" which can improve capturing sedentary time (ActiLife, 2010). Participants wore the GT3X along with an earlier model, AM7164, for 24-hours only removing when engaging in water activities. The cutpoints to classify PA intensities were a mix between Freedson, Hendelman, and Yngve. (Freedson et al., 1998; Hendelman et al., 2000; Yngve et al., 2003). There was a significant difference in sedentary, light, and vigorous intensities between AM7164 and GT3X with LFE disabled ($p<0.05$) (Table 4). When the LFE was enabled, the differences in light intensities and sedentary time were reduced, but a significant difference in vigorous intensity still remains between the AM7164 and GT3X ($p<0.05$) (Table 4). These results suggest there are significant differences between light and vigorous intensities as well as sedentary time between the AM7164 and the

GT3X; however, if the LFE option is enabled, the differences could be mitigated between the two devices.

Table 4

Mean minutes in PA intensities

Intensity	AM7164	GT3X	GT3X (LFE)
Sedentary	1198.9 ± 63.0	1224.5 ± 54.4*	1196.4 ± 61.8
Light	195.7 ± 48.3	172.1 ± 39.7*	197.6 ± 46.0
Moderate	37.7± 19.4	38.0 ± 19.2	40.7 ± 22.0
Vigorous	6.3 ± 11.0	4.5 ± 9.7*	4.9 ± 10.0*
Moderate-to-Vigorous	43.9 ± 28.2	42.5 ± 26.4	45.6 ± 29.8

*- A significant difference compared to AM7164

Cain et al (2013) conducted a similar study as Reid-Larson (2012) with some modifications to the methodology. The participants were instructed to wear the accelerometers for a total of three days instead of one, but participants were able to remove the accelerometer while sleeping. Freedson's cutpoints were the only ones used to classify PA intensities. There was a significant difference in time spent in sedentary, light and moderate intensities between the AM7164 and GT3X with LFE disabled (Table 5). When LFE was enabled, there were no significant differences across intensities for AM7164 and GT3X. In order to increase sensitivity for lower intensity activity, the LFE option should be enabled.

Table 5

Mean minutes per day in PA intensities

Intensity	AM7164	GT3X	GT3X (LFE)
Sedentary	453.4	478.9*	449.8
Light	248.3	217.1*	243.9
Moderate	26.7	23.5*	26.1
Vigorous	6.1	6.3	6.5

*- A significant difference compared to AM7164

The results from Reid-Larson and Cain studies suggest the LFE option can better classify lower intensity activity. This is especially important when trying to compare results from previous studies. In the past 15 years, the majority of population-based studies have used the AM7164 model more frequently than any other Actigraph model (Cain et al., 2013). As more researchers switch to the GT3X, it is imperative to have the capabilities to compare past research to studies currently conducted to examine the shift in PA as more guidelines continue to develop.

2.2.4.4. Reliability of Accelerometers

As accelerometers become widely accepted to obtain objective information about PA levels in humans, more studies need to investigate the reliability of these monitors. It is crucial to consider if the GT3X monitors have the same reliability between the monitors. To date, few studies have investigated the intra-and inter-instrument reliability along with the inter-trial reliability of the GT3X, specifically.

2.2.4.4.1. Laboratory Environment

Reliability for accelerometers should initially be conducted in a controlled environment. These studies have been primarily regulated to mechanical trials such as vibration tables where no external forces can determine the variance within each device (Esliger & Tremblay, 2006). The external forces might include device placement or gait characteristics. Initial reliability testing should be mechanically tested before shifting to the reliability of the device to detect human movement.

One study explored the intra-and inter-instrument reliability of the GT3X using mechanical testing (Santos-Lozano et al., 2012). Ten GT3Xs were randomly selected from a batch of 50 brand new monitors. Each device was securely fastened to a vibration table to avoid additional movement and misalignment of the accelerometer. For each trial, the accelerometer was fastened so the vibration could only occur on the Y-axis (vertical), X-axis (anterior-posterior), and Z-axis (medio-lateral). After securely fastening the device, the vibration table was activated. Different frequencies (1.1, 2.1, 3.1, 4.1, and 10.2 Hz) representing human movements were applied to the devices lasting seven minutes. To assess intra-instrument reliability, the coefficients of variations (CVintra) were calculated from each device for minutes two through six (researchers dropped the first and last minute of data collection). Intra-class correlation coefficients (ICC) were used to test the inter-instrument reliability; as the ICC approaches one this indicated the reliability of the monitor. The values for CVintra were lowest for 3.1 Hz and highest for 10.2 Hz (Table 6). The lowest CVinter frequencies were 2.1, 3.1, and 4.1 Hz (Table 7). The ICC for Y, X, Z axes across all frequencies were 0.98, 0.99, and 0.98, respectively. Similar to the CVintra frequencies, the CVinter frequencies were lowest for 2.1-4.1 Hz. Overall, the optimal frequencies for high intra- and inter- reliability occurred between 2.1-4.1 Hz. Thus, the GT3X is an accurate device to quantify PA intensities between those frequencies, which correlate to typical human movement.

Table 6

Intra-instrument coefficient of variation for the mean activity counts

Frequency	Axis		
	Y (%)	X (%)	Z (%)
1.1	18.5	0.4	11.5
2.1	1.3	1.7	2.5
3.1	0.8	0.4	0.6
4.1	1.3	0.8	1.1
10.2	27.3	22.5	8.6

Table 7

Inter-instrument coefficient of variation for the mean activity counts

Frequency	Axis Y (%)	X (%)	Z (%)
1.1	201.8	287.0	149.4
2.1	3.1	9.9	9.2
3.1	2.2	1.2	1.5
4.1	3.7	7.6	6.8
10.2	67.3	99.5	52.6
Overall mean	55.6	81.0	43.9

Loranzo et al. (2014) were the first group of researchers to scrutinize inter-trial reliability of the GT3X monitors. Eight different monitors were randomly selected from a batch of 50 monitors. One participant wore all eight monitors at the same time on two separate testing days and engaged in five different activity bouts for 12 minutes with 10 minutes rest between each bout. The activities performed were: walking at 4 km/h, walking at 6 km/h, running at 8 km/h, running at 10 km/h, and 40 cycles/minutes of sit-to-stands on the beat of a metronome. The intra-class correlation coefficients (ICC) for the Y-axis (vertical), X-axis (anterior-posterior), and vector magnitude (VM) were all above 0.80 and statistically significant ($p<0.01$) across all bouts (Table 8). For the Z-axis (medio-lateral), however, the ICCs were below 0.80 for the sit-to-stands, walking at 4 km/h, and running at 10 km/hr. Although the values were below 0.8, all values were still classified as fair or good and were statistically significant ($p<0.01$). A repeated measures ANOVA was applied to examine the differences between the two data collections days for all activities. There was a significant interaction effect for trial X condition in each axis ($p<0.01$). Further, the Bonferroni adjustment found significant differences ($p<0.01$) between trials in sit-to-stand, 4 km/hour, 6 km/hour, and 8 km/hour. Researchers should carefully assess these results realizing there was only one participant involved. These results concluded the GT3X would be capable for detecting activities in moderate- and vigorous-intensities, but the researchers cautioned against using this particular accelerometer for sedentary or light-intensity activities in predominately sedentary populations.

Table 8

Inter-instrument coefficient of variation for the mean activity counts

	Sit-Stands	4 km/h	6 km/h	8 km/h	10 km/h
Y-axis	0.895	0.848	0.808	0.973	0.869
X-axis	0.964	0.964	0.902	0.906	0.908
Z-axis	0.696	0.576	0.873	0.868	0.611
VM	0.810	0.977	0.821	0.968	0.892

2.2.4.4.2. Free-Living Environments

After the GT3X has been shown to be a reliable monitor under mechanical environments, research has shifted to focus on reliability under “real world” conditions. Jarret and colleagues (2015) were the first to explore intra- and inter-instrument reliability for the GT3X under free-living conditions. Nineteen adults wore two devices on their left and right hip during waking hours for a 24-hour period. The participants were recruited to wear the devices for at least 13 hours with a minimum of 30 minutes of moderate intensity ambulatory activity allowing participants to engage in a wide spectrum of activities. Data were reduced using nonwear-time criteria of greater than or equal to 60 minutes of consecutive zeros and scanned for unintentional data greater than 1250 counts/5 seconds. Intra-class correlation coefficients (ICCs), coefficient of variation (CV), and absolute percent difference (APD) were calculated to examine if the values from the left and right hip were similar. Ninety-five percent limits of agreement (LoA) were used to measure inter-instrument agreement. A paired t-test indicated there was no significant difference between PA intensities in regards to the placement of the device (p>0.05). The ICC values spanning across the different intensity levels determined by the specific cutpoints were very high at .97-.99. The CVs for vigorous and very vigorous intensities were high but if they were combined into moderate-to-vigorous physical activity (MVPA), the CV was reduced to

2.85%. Again, if vigorous and very vigorous were combined into MVPA, the APD was reduced to 4.05%. The mean bias and the 95% LoA demonstrated that the LoA became wider as the intensity increased, but collapsing the data to MVPA reduced the mean bias and narrowed the 95% LoA (Table 9). Overall, the results suggest the reliability of the GT3X in a free-living environment is lower in higher intensities but can be improved when combined into MVPA.

Table 9

Limits of Agreement

	95% LoA
<Moderate	3.54 to 10.91
Moderate	6.08 to 18.94
Vigorous	15.87 to 48.14
Very Vigorous	19.81 to 62.16
Moderate-to-Vigorous	5.14 to 15.76

Comparatively, researchers replicated the previously discussed methodology to test the inter-instrument reliability (Aadland et al., 2015). Eighty-seven participants wore one accelerometer for 21 days alternating between the right and left hip every 10 days. Data were analyzed using 10-second epochs with a wear time of greater than or equal to 480 minutes per day. The minimum number of days accumulated by the participant for the 7-day and 21-day periods were three and nine days, respectively. Nonwear time was classified as greater than or equal to 60 minutes of consecutive zeros allowing for less than two minutes of non-zero counts. Metzger's cutpoints were used to determine PA intensity levels. Inter-instrument reliability was analyzed for wear time, PA intensities, and counts/minute (CPM) from the vertical axis. Inter-instrument agreement was analyzed by computing absolute means of agreement, standard error of measurement (SEM), 95% LoA, percentage typical error, and Pearson product-moment correlation coefficient (r). The linear mixed model regression analysis indicated there was no statistical difference between right or left hip locations ($p>0.05$). The correlation between the accelerometers was very high for one, seven, and 21 days of data (r= 0.9-1.0). The SEM and 95% LoA decreased for wear time, PA intensities, and CPM as more days of data were accumulated. There was a 14-48% improvement when comparing one to seven days of data with an even greater improvement from one to 21 days of data (47-69%), which demonstrated the measurement error decreased when PA days was accumulated over several days. Therefore, the results indicate that the GT3X is a reliable monitor for measuring PA level and intensity specific activities.

2.2.5. International Physical Activity Questionnaire

Although the accelerometer is a reliable and valid objective measure, it is not always the most feasible way to examine PA levels. Establishing a singular mechanism is especially critical when physical inactivity is considered a global health crisis (Pate et al., 1995). Establishing a single mechanism that can be used to investigate PA across different populations around the world became a vital part of PA research. The development of the International Consensus Groups became the lead investigating unit to establish a self-reported measure of PA that could be transparent across populations around the world (Craig et al., 2003). As a result, the International Physical Activity Questionnaire (IPAQ) was established.

The IPAQ is a well-established and frequently used PA surveillance instrument for modern and developing countries (Basset, 2003). There are short (IPAQ-S) and long (IPAQ-L) versions that have been translated into several different languages with the potential to be modified to "culturally relevant" moderate and vigorous PA intensities (Craig et al., 2003). The survey was designed to assess PA for 18-65 year olds. The IPAQ-S and IPAQ-L forms are retrospective surveys asking the participants to recall the PA that occurred during the last three days and seven days, respectively. The IPAQ-S assesses nine different items examining time spent walking in moderate- and vigorous-intensities whereas the IPAQ-L examines 31 items across five different domains: job-related PA, transportation PA, housework and house maintenance, leisure-time PA, and time spent sitting (Craig et al., 2003). Therefore, results from the IPAQ can measure PA and physical inactivity for cross-national monitoring.

The IPAQ-S and IPAQ-L were developed to be international PA surveillance instruments; thus, it is important to examine its reliability and validity against an accelerometer in multiple countries (Craig et al., 2003). The IPAQ-S and IPAQ-L demonstrated a repeatability coefficient of p=0.76 (95% CI: 0.73-0.77) and p=0.81 (95% CI: 0.79-0.81), respectively. These coefficients suggest both IPAQ forms are capable of attaining the same results after each occurrence. The validity of the IPAQ was tested against the criterion measure, the Computer Science Application Inc. accelerometer (CSA model 7164), which was the first edition of the GT3X. The Freedson 1998 cutpoints were applied to the CSA data to classify the duration of intensity each participant engaged in for the three or seven day protocol. The pooled data to assess the validity of the IPAQ-S and IPAQ-L forms against the CSA were p=0.33 (95% CI: 0.26-39) and p=0.30 (95% CI: 0.23-0.36), respectively, revealing a moderate agreement between the two measures. Therefore, either form of the IPAQ can be used as a surveillance mechanism to monitor PA levels across different populations.

2.2.6. Physical Activity Conclusion

There are several mechanisms to monitor activity levels in adults that can be used to further understand the dose-response relationship between PA and negative health outcomes. It is vital researchers continue to improve these instruments to understand the importance of increasing PA across all adults. Because adults in the United States spend the majority of their day in sedentary pursuits, it is imperative to understand the potential negative health outcomes associated with physical inactivity (Matthews, 2008). In addition, physical inactivity in individuals who chose a career which demands a high level of fitness may lead to negative health outcomes for the general population. Thus, further research regarding obesity and PA are required in order to assist with evidence-based recommendations for the general public and career-specific organizations.

2.3. Firefighters

Firefighters are responsible for protecting citizens as well as the infrastructure of cities across the United States. In order to safely protect and perform on-duty tasks, firefighters must be capable of performing the physiologically demanding jobs. Formal exercise and PA research specific to firefighters is lacking. Firefighters, as well as the general public, are at risk for negative health outcomes because researchers have not formally investigated the many physiological facets of job-specific tasks.

2.3.1. Firefighters' National Guidelines

2.3.1.1. Demographics

The number of registered career and volunteer firefighters in the United States reached an historical milestone surpassing 1,134,000 (Haynes & Stein, 2016). A mere 1/3 (31%) of the 1,134,000 are career firefighters who are responsible for protecting over 2/3 of the United States infrastructure and population. Despite an increase in the number of firefighters, the occupation still remains predominantly male with females only accounting for 8% of all registered firefighters. Although career firefighters are responsible for the majority of fire protection and medical care, there are no federal entities responsible for governing policies or procedures.

Research on firefighters depicts the difference between on-duty and off-duty injuries or causalities. The NFPA defines on-duty as: "1) being at the scene of an alarm, whether a fire or non-fire incident (including emergency medical calls); 2) responding to or returning from an alarm; 3) participating in other fire department duties such as training, maintenance, public education, inspections, investigation, court testimony or fund raising; and 4) being on call or stand-by for assignment at a location other than at the fire fighter's home or place of business" (Fahy, LeBlanc, & Molis, 2016, p. 1). Additionally, the NFPA defines on-duty fatalities as "any injury sustained in the line of duty that proves fatal, any illness that was incurred as a result of actions while on duty that proves fatal, and fatal mishaps involving nonemergency occupational hazards that occur while on duty" (Fahy, LeBlanc, & Molis, 2016, p. 1).

2.3.1.2. National Recommendations

The National Fire Protection Association (NFPA) serves as a pseudo governing body for all United States firefighters. The NFPA was established to develop voluntary codes and standards to protect the overall well-being of firefighters and citizens from preventable injuries and death. In 2000, Congress funded the National Institute for Occupational Safety and Health (NOISH) to examine firefighter fatalities and prevention programs (NIOSH Alert, 2007). Based on the report by NIOSH, NFPA developed code 1582, *Standard on Health-related Fitness Programs for Firefighters*. This guideline advises fire departments to create and provide health-related fitness programs to promote and sustain high fitness levels within the department. Additionally, code 1582 recommends each department have its own supervising physician to inform the chief if a candidate or current fire fighter is medically cleared to safely perform his/her job. Furthermore, the fire department physician is responsible for in-depth evaluations including medical history, examination, and laboratory tests to detect conditions which could diminish candidates' or current firefighters' ability to adequately respond to emergency situations (NFPA, 2007). Although these codes are meant to improve the overall quality of life in firefighters, the codes are not mandated and thus departmental personnel choose which components to follow.

The research following the implementation of NFPA code 1582 enabled officials to set a minimum standard for cardiorespiratory fitness. Although the research is not described in detail, officials concluded an exercise tolerance, as measured by VO_{2max}, of 42 ml/kg/min as the minimum threshold to ensure firefighters are capable of safely engaging in job-related tasks. It was proposed that firefighters who do not meet the minimum standards or had other coronary artery disease (CAD) risk factors should be reassigned to less strenuous positions. The 1582 measures were suggested to reduce the number of preventable on-duty fatalities.

2.3.1.3. Sudden Cardiac Death in Firefighters

In the past 38 years, the number one contributor to on-duty fire fighter fatalities was sudden cardiac death (Fahy et al., 2016). Sudden cardiac death (SCD) occurs when a person's heart suddenly loses function either with or without a previous condition associated with heart disease (Heart Attack or Sudden Cardiac Arrest, 2015). Fahy (2005) reported 440 (44%) of all annual on-duty deaths from 1995-2004 were due to sudden cardiac death. There has been more emphasis from national entities to reduce cardiac fatalities. Reports from 2015 indicate close to 50% of deaths were still attributed to SCD (Fahy et al., 2016). Although the overall number of on-duty deaths has declined, the risk of a cardiac event still remains relatively high.

An important sub-component of the job demands of a fire fighter is the on-going training for career firefighters. Training exercises involve a wide variety of tasks including fitness and agility testing as well as formal exercise at the fire station. Although the number of overall on-duty deaths is steadily declining, the number of deaths during training activities remains the same (Fahy, 2012). Of the 108 training deaths from 2001-2010, 56 (53%) were diagnosed as sudden cardiac fatalities. Of the 56 sudden cardiac fatalities, 24 of the fatalities, or just under half, occurred during fitness training exercises. Interestingly, less than half (11 of the 24) of the firefighters were members of departments with mandated annual physical examinations. Therefore, it is necessary examine ways to mitigate sudden cardiac deaths when firefighters are completing rigorous training regimes.

Separate reports from the NFPA and NIOSH developed necessary steps that must be taken to mitigate the risk of sudden cardiac deaths among firefighters. The heart attack prevention steps for firefighters are: “1) conduct annual medical evaluations; 2) screen for CAD risk factors; 3) conduct exercise stress tests for firefighters with multiple CAD risk factors; 4) give appropriate treatment for CAD risk factors; and 5) restrict the job tasks that firefighters with positive stress tests are allowed to perform” (Fahy, 2012, pg.2). If these steps are properly implemented within departments nationwide, the number of preventable sudden cardiac deaths could be abated.

One of the major causes of disability and death in the world is attributed to CHD (Rosamond et al., 2007). There is evidence to suggest that fitness is a strong predictor of cardiovascular disease (CVD) risk factors along with CVD morbidity and mortality (Lavie et al., 2009; Lee et al., 2011; Kodama et al., 2009). CRF is typically used to assess physical fitness within individual (Noonan & Dean, 2000; Wyndham, 1967). A recent meta-analysis systematically reviewed the quantitative relationship between CRF and all-cause mortality and CHD or CVD events in healthy individuals (Kodama, 2009). The analysis consisted of 33 studies with more than 100,000 participants. The pooled risk ratio (RR) data revealed that for each 1-MET increase in maximal aerobic capacity, there was a 13% and 15% reduced risk of all-cause mortality (RR: 0.87, 95% CI: 0.84-0.90) and CHD/CVD event (RR: 0.85, 95% CI: 0.82-0.88). More specifically, participants with low CRF had a 70% (95% CI: 1.51-1.92, $p<0.001$) increase of all-cause mortality and 56% (95% CI:1.39-1.75, $p<0.001$) increase of CHD/CVD events compared to participants with high CRF. Therefore, it is crucial to increase CRF to mitigate the risk of all-cause mortality and CHD/CVD events.

2.3.2. Physiological Demands of Job Tasks

Firefighters have a physiologically demanding occupation (Elsner & Kolkhorst, 2008). When firefighters arrive at a scene they are expected to perform an array of tasks that might include: unraveling the hose to attach to a fire hydrant, operating high pressure hoses to extinguish a fire, maneuvering ladders to rescue people from buildings, ventilating smoke from buildings, and providing medical care (Elsner & Kolkhorst, 2008). Further, firefighters are expected to perform these tasks while wearing their turnout gear which includes: insulated coat and pants, waterproof boots, hood, helmet, gloves, and/or a self-contained breathing apparatus (SCBA). The additional weight of the turnout gear, approximately 20-50 pounds, will increase the physiological demand of performing job-specific tasks for firefighters. Thus, it is vital to understand the level of CRF specific for firefighters to effectively and safely perform expected job duties.

Several researchers have investigated the demand of fire suppression tasks on CRF level (Baker, Grice, & Matthews, 2000; Dreger, Jones, & Peterson, 2006; Elsner & Kolkhorst, 2008; Gledhill & Jamnik, 1992; Lemon & Hermiston, 1977; Sothmann et al., 1990; von Heimburg, Rasmussen, & Medbo, 2006). Two of the studies had firefighters complete tasks that were less than two minutes (Lemon & Hermiston, 1977; Glendhill & Jamnik, 1992), which can cause an underestimation of $VO_{2\ max}$ as it takes roughly two to three minutes for VO_2 to reach steady state with the onset of exercise (Kolkhorst et al., 2004). Glendhill and colleagues (1992) asked firefighters to participate in 27 tasks of which 13 required more than two minutes to complete. The lowest VO_2 (16.84 ml/kg/min) was for hoisting the fly section of a 15-m ladder while the highest VO_2 (44.0 ml/kg/min) was carrying a high-rise hose pack and multipurpose tool up high-rise starts. Unfortunately, additional details regarding other job-specific tasks have not been reported in the literature.

Additional studies implemented protocols that would mimic the duration and tasks of a typical fire emergency (Sothmann et al., 1990; von Heimburg, et al., 2006). A study conducted for the NFPA revealed the average duration of fire suppression tasks for a live fire emergency was nine minutes and 57 seconds (Gempel & Burgess, 1977). Sothman and colleagues (1990) developed a protocol with seven fire suppression tasks with the duration of 8.9 ± 2.4 minutes. The mean VO_2 for completing the protocol was 30.5 ± 5.7 ml/kg/min. It is important to note that the VO_2 was representative for the protocol as each individual task was completed in less than two minutes before reaching steady state.

As technology has improved, the use of portable metabolic carts renewed the interest of energy expenditure on fire suppression tasks. Firefighters were asked to participate in a rescue simulation of six victims where they had to climb six flights of stairs. The firefighters were able to complete the rescue simulation in 4.9 ± 1.0 minutes with an average VO_2 of 44 ± 5.0 ml/kg/min (von Heimburg et al., 2006). The rescue simulation required 83 ± 7 % of firefighters' $VO_{2\ max}$. Another study increased the number of fire suppression tasks to 11 but did not include a rescue simulation as one of the tasks (Holmer & Gavhed, 2007). Each fire fighter was asked to complete all tasks as quickly as possible with an average completion time of 22 minutes and 17 seconds. The task with the highest VO_2 (33.5-55.1 ml/kg/min) was the tower climb of three flights of stairs, and the average VO_2 for the whole protocol was 25.6-42.7 with an average of 33.0 ml/kg/min.

Elsner and colleagues (2008) not only used a similar seven-task protocol but also measured each firefighter's true $VO_{2\ max}$. The time to complete the simulated task protocol was 11.56 ± 5.0 minutes. The average VO_2 for the whole protocol was 29.1 ± 8.0 ml/kg/min, which was roughly 65% of their $VO_{2\ max}$. The Pearson product-moment correlation was used to examine the relationship between the treadmill $VO_{2\ max}$, performance time for completing the protocol, and average VO_2 for the protocol. Firefighters who had a higher $VO_{2\ max}$ finished the protocol in less time (r= -0.725, 95% CI: -0.416, -0.884). Additionally, firefighters with higher CRF completed the protocol expending more energy (r=0.355, 95% CI: 0.295-0.35). Thus, firefighters who engaged in fire suppression simulated tasks were more likely to complete the tasks faster if they have higher CRF levels.

Aging firefighters have also experienced a decline in CRF (Baur et al., 2011). There is a silver lining, however, that PA and levels of adiposity have shown to lessen the effect of age (Baur et al., 2012). Regardless of age, higher BMI was associated with lower CRF levels. If the firefighters were classified as obese (>30) but still attained at least 150 minutes a week of MVPA, they were able to maintain higher CRF than their obese peers who did not reach the 150 minutes of MVPA. These results demonstrate that PA and adiposity can attenuate the effect of age on CRF in firefighters. In order for firefighters to perform their fire suppression tasks as they age, they need to maintain an appropriate weight and/or reach at least 150 minutes of MVPA per week.

As people age, there is a decrease in maximal heart rate, stroke volume, cardiac output, and decreased fat mass all of which contributes to the decline if $VO_{2\ max}$ (Proctor & Joyner, 1997). Hakola and colleagues (2011) used a cross-sectional design to investigate the decrement of $VO_{2\ max}$ with increasing age. The participants (n=1348) ranged in age from 57-78 years old and were asked to perform a cycle ergometer $VO_{2\ max}$ test. For every one year increase in age, the VO_{2max} decreased by 1.6%. High levels of CRF play a vital role for decreased morbidity; thus, it is vital to understand ways to proactively mitigate the effects of age.

2.3.3. Obesity Levels in Firefighters

Incorporating BMI into the research protocol has revealed roughly 75% of all firefighters are overweight with 40% classified as obese (Baur et al., 2011; Clark et al., 2002; Durand et al., 2011; Soteriades et al., 2008; Tsismenakis et al., 2009; Poston et al., 2011). Furthermore, a population-based cohort study determined volunteer and career firefighters were more likely to be overweight or obese than the general U.S. population (Poston et al., 2011). As the rise in obesity continues, there needs to be more emphasis on reducing excess weight in firefighters so they are capable of safely and sufficiently engaging in their demanding job-specific tasks.

Obesity is a common cardiovascular disease risk factor associated with cardiometabolic risk factor clustering (Wildman et al., 2008). Cardiometabolic risk factor clusters include: elevated blood pressure; elevated triglycerides, fasting glucose, and high-sensitivity C-reactive protein; elevated homeostasis model assessment of insulin value; and reduced high-density lipoprotein cholesterol (HDL-C) level. In addition to cardiometabolic risk factors, the rise in obesity levels in firefighters has been associated with job-related disability (Soteriades et al., 2008), incident CHD (Glueck et al., 1996), on-duty CHD events (Geibe et al., 2008), and CVD retirements (Holder et al., 2006). Consequently, as firefighters continue to be overweight, concerns about their physical fitness and physical inactivity have become a priority.

BMI is a widely used measure in epidemiological research examining the differences between normal weight, overweight, and obese individuals (Kuczmarski & Flegal, 2000; Moren et al., 2000; Sanowski et al., 2000). Studies have demonstrated the use of BMI for categorizing weight status in firefighters is acceptable (Clark et al., 2002; Poston et al., 2011). Specifically, Poston et al (2011) discovered obesity was even more prevalent when using percent body fat, which was measured using bioelectrical impedance instead of BMI. Therefore, BMI is an acceptable measure for assessing whether firefighters are overweight or obese and may be a conservative measure and estimate obesity in firefighters.

Additionally, an increase in BMI can also be associated with adverse health outcomes in firefighters. In firefighters, there is a significant, direct association with an increase in BMI and systolic blood pressure (SBP), diastolic blood pressure (DBP), cholesterol, cholesterol/high density lipoprotein (C/HDL) ratio, triglycerides, and VO_{2max} (Table 10) (Clark et al., 2002). Firefighters who were classified obese (class 1) were 2.71 times more likely than their normal weight counter parts to have SBP ≥ 130 mmHg (Poston et al., 2011). Firefighters who were classified as obese (class 1) were 4.29 times more likely than their normal weight counter parts to take hypertension medication (Poston et al., 2011). As a result, BMI is an adequate measure to examine associations in negative health outcomes associated with obesity.

Table 10

Linear Regression Model: Predictors of CRF (Maximal METS)

Health Outcome	Normal Weight (n=42)	Overweight (n=106)	Obesity (Class 1 & 2) (n=65)	Obesity (Class 3) (n=5)	ANOVA *p*-value
SBP	116.4 ± 10.1	122.6 ± 11.5	123.1 ± 10.0	128.0 ± 13.0	<0.05
DBP	73.3 ± 8.4	76.2 ± 8.0	78.8 ± 7.3	88.8 ± 7.6	<0.05
Cholesterol	173.5 ± 25.0	203.8 ± 37.6	206.0 ± 35.5	188.4 ± 23.9	<0.05
HDL	45.5 ± 9.4	49.9 ± 25.0	45.6 ± 17.7	52.8 ± 7.3	>0.05
C/HDL	3.9 ± 0.9	4.7 ± 1.4	5.1 ± 1.3	3.6 ± 0.6	<0.05
Triglycerides	92.0 ± 48.0	158.8 ± 132.2	171.3 ± 91.8	137.8 ± 85.3	<0.05
VO_{2max}	48.6 ± 3.8	45.1 ± 4.5	41.7 ± 3.9	37.0 ± 2.8	<0.05

As a result of increased obesity levels, firefighters have also experienced a decline in fitness levels resulting in a decreased ability to safely and efficiently perform job-specific tasks. Studies have demonstrated roughly 25-60% of firefighters do not meet the NFPA minimum guidelines for fitness (42 ml/kg/min), which suggests these firefighters would not be able to successfully perform job-specific tasks (Baur et al, 2012; Donovan et al., 2009; Durand et al., 2011). Furthermore, firefighters who have superior fitness levels have been shown to complete job-specific tasks faster and more efficiently than their less fit cohorts (Elsner et al., 2008). Thus, more emphasis needs to be placed on improved fitness levels and increasing the amount of physical activity to protect each firefighter.

2.3.4. Physical Activity in Firefighters

Inadequate amount of PA and exercise is a common issue for firefighters (Durand et al., 2011). Results from one study revealed only 20% of firefighters were meeting ACSM's PA guidelines (Durand et al., 2011). These results emphasize the need to further investigate the outcomes of insufficient PA levels in the firefighter population.

Currently, there are few studies investigating the effects of leisure-time physical activity (LTPA) on cardiorespiratory fitness (Baur et al, 2012; Durand et al., 2011). A cross-sectional cohort study encouraged 527 firefighters to complete a graded exercise test (GXT) using Bruce or modified Bruce protocols with a supplementary activity questionnaire that investigated: frequency, duration, and intensity of exercise (Durand et al., 2011). The majority of the firefighters (63%) met the NFPA minimum guideline for CRF 42 ml/kg/min. Although the methodology did not incorporate job-specific tasks, researchers suggested firefighters would have the ability to perform tasks efficiently.

BMI was used to classify over 80% of the 527 firefighters as overweight or obese. The researchers reported large number of overweight or obese firefighters, which resulted in adverse associations between PA domains and CRF. The increase in intensity, frequency, and duration were significantly associated with maximal METS achieved (MaxMETs) after adjusting for BMI, age, and smoking status (p<0.001). Additionally, total weekly exercise (minutes/week) was significantly associated with MaxMETs after adjusting for BMI, age, smoking status, and physical exercise intensity (β=0.0024, p<0.001). The results from this study suggest that certain domains of PA are associated with increased CRF.

A comparable study (n=804) included a similar methodology of Durand and colleagues (2011), however, the type of CRF testing used to examine the effects of increased PA differed (Baur et al, 2012). CRF was analyzed using total exercise tolerance test time (T) instead of gas analysis in the following equation: VO_2 (ml/kg/min) = 14.76 – (1.379(T)) + (0.451(T^2)) – (0.012(T^3)). The same PA survey used in Durand's research was incorporated to assess specific aspects of exercise. The results suggested exercise durations were positive predictors of CRF (Table 11). The results again proposed that there is a significant association between increased aspects of exercise and CRF.

Table 11

Linear Regression Model: Predictors of CRF (Maximal METS)

Variable	Parameter Estimate	Standard Error	*p*-value
Age	-0.058	0.010	<0.0001
BMI	-0.211	0.019	<0.0001
Total Weekly Duration	0.008	0.0002	0.0003
Duration of Weight Lifting	0.189	0.0639	0.0032
Intensity of Exercise	0.213	0.123	0.0878

It is important to note that the previous studies investigated aspects of exercise rather than PA. Participants were asked to answer the following components in a forced choice survey: minutes per cardio session, minutes per weight training session, intensity of training, and weekly exercise frequency. These questions were used to specifically target exercise instead of PA. Additionally, the survey did not include certain domains of PA such as: occupational, transportation, household, and leisure-time PA, which is an important aspect as firefighters' jobs encompass these domains. Thus, researchers should develop additional questions to the previous survey or use other valid surveys like to IPAQ to assess all domains of PA.

The majority of a firefighter's day is spent in sedentary or light activities, which does not adequately prepare them for the more rigorous tasks that can occur when the station's alarm sounds. Firefighters spend most of their day maintaining the station and preparing the trucks for potential calls. While maintaining the station, firefighters are expected to preform typical household chores such as sweeping, mopping, and dusting. In addition to maintenance, some stations have workout facilities to comply with NFPA code 1582 to promote increased fitness levels (NFPA, 2007). There is an even greater physiological shift when the alarms are activated because firefighters typically remain in sedentary and light physical activity intensities throughout their day.

After the alarm is triggered, firefighters are expected to promptly mobilize. The sudden shift in response is thought to activate the sympathetic nervous system causing a surge in the fire fighter's heart rate (Barnard & Duncan, 1975; Kuorinka & Korhonen, 1981). The initial spike in heart rate remains in prolonged tachycardia throughout fire suppression tasks with transient ST-segment changes, which possibly indicates myocardial ischemia (AlZaiti et al., 2015; Barnard & Duncan, 1975; Duncan et al., 1979). These physiological derangements can lead to potential myocardial infarctions resulting in sudden cardiac death (Rubart & Zipes, 2005). After an exhaustive literature review, it has been found there are physiological changes in firefighters when performing on-the-job-tasks. However, there is little literature that specifically targets increasing PA levels to mitigate the negative healthy outcomes when engaging in fire emergencies.

2.5. Conclusion

In the United States, the obesity epidemic and physical inactivity can lead to adverse health effects. The official genetic and non-genetic causes of obesity are currently inconclusive; however, there is promising evidence for increasing PA, which could alleviate excess weight gain. Focusing on occupational PA is beneficial as the majority of waking hours for adults are spent at their job. Thus, investigating the amount of PA firefighters accumulate while at their job could lead to better insight as to what is causing the increased obesity epidemic within firefighters. Not only will PA measurements be beneficial for obesity but also for examining why some firefighters are not meeting the NFPA national guidelines for CRF. This proactive approach will also give much needed insight for improving cardiovascular health in firefighters. Additionally, as the number of medical calls continues to rise, it is imperative to understand how CRF levels in firefighters affects their ability to perform quality life-saving measures for community members.

CHAPTER 3. METHODOLOGY

In the United States, there is a growing concern for the economic and health care crisis that has resulted from the rise in obesity (Cawley & Meyerhoefer, 2012; Church et al., 2011; Finkelstein et al., 2009; Lavie et al., 2009). In the past four decades, the prevalence in classifying adults as overweight or obese has shifted from fewer than 25% to nearly 70% (Flegal et al., 2010; Kuczmarski et al., 1994; Ogden et al., 2015). One of the detrimental effects of obesity is the increased risk of all-cause mortality (Flegal et al., 2013). After several decades of research, however, multiple causes have been linked to obesity (Han et al., 2010; Walley et al., 2009). Thus, researchers are continually exploring ways to decrease obesity levels to improve overall health.

Physical activity is one modifiable lifestyle behavior that has been identified to decrease obesity and negative health outcomes. Large, prospective, primary prevention studies concluded active men were less likely to have coronary heart disease, hypertension, and all-cause mortality than their less active counterparts (Paffenbarger et al., 1978; Paffenbarger et al., 1983; Paffenbarger et al., 1986). Although negative health outcomes could be mitigated by physical activity, only one in 20 Americans are meeting the American College of Sports Medicine's (ACSM) physical activity guidelines (Troiano et al., 2008).

Emerging evidence has led to an increased concern for firefighters' increased obesity levels and decreased physical activity (Clark et al., 2002; Durand et al., 2012; Poston et al., 2011). Formal exercise and physical activity research specific to firefighters is lacking. More specifically, there is a lack of literature using accelerometers to measure physical activity objectively. There is more evidence, however, to demonstrate firefighters have a high prevalence of obesity that surpasses the general population (Poston et al., 2011). Thus, firefighters, as well as the general public, are at risk for negative health outcomes because researchers have not formally investigated the many physiological facets of job-specific tasks.

3.1. Purpose

The primary purpose of this study was to understand associations for physical activity levels and obesity on cardiorespiratory fitness (CRF). The secondary purpose of this study was to investigate how physical activity differentiates between on- and off-duty days.

The research was guided by the following questions:

1. Do physical activity intensity levels, body mass index, and/or waist circumference predict cardiorespiratory fitness in career firefighters?
2. How do physical activity intensities differ between on- and off-duty days in career firefighters?

A cross-sectional design was used for this study. The independent variables were the firefighters' PA intensities and anthropometric measures. The dependent variable was CRF.

3.2. Participants

Thirty male participants were recruited from a fire department in a mid-sized, Midwestern, city. The fire department which agreed to participate in the study currently has no female firefighters in a position other than administration; therefore, only males were analyzed in this particular study. Participants were recruited through informational meetings held at the fire stations. Each participant must be an active member of a Midwestern fire department between the ages of 20-55 years old. If the participant had a current injury or medical condition which precludes the firefighters from performing active, on-duty tasks; previous medical concern from prior graded exercise tests; or, inability to perform treadmill walking with issued bunker gear, he was not be able to participate in the study.

3.3. Documentation

Prior to the start of data collection, the Institutional Review Board at North Dakota State University approved the study. A research assistant read the informed consent and clarified any questions with each participant has before he signed the document (Appendix A). Physical activity data was monitored at any location (including personal residence) as the accelerometer was worn during all activities in order to capture typical behavior patterns. Data collection was conducted in the Human Performance Laboratory (HPL) at North Dakota State University, 1301 Centennial Blvd., Fargo, ND 58102. Data was collected in the HPL as the laboratory is equipped with treadmills, a metabolic cart, and heart rate monitors. The HPL is also large enough to house the CPR Resusci Anne so the participants had plenty of room to perform CPR.

3.4. Procedures

A research assistant distributed ActiGraph GT3X+ (ActiGraph, Pensacola, FL, USA) accelerometers with adjustable elastic waistbands to the participants at their respective fire stations. Participants also received sleep logs (Appendix B) and were given an IRB-approved informed consent at this time. The participants wore the GT3X+ accelerometer for nine days to capture all of the activities for which a participant engaged in during on- and off-duty time. Upon completion of wearing GT3X+ accelerometer for nine days, participants reported to NDSU for one data collection session.

For the data collection session, participants reported to the HPL for approximately one hour. The participants returned their GT3X+ acclerometer and completed the International Physical Activity Questionnaire (IPAQ) and a demographic questionnaire (Appendix C). Upon completion of the surveys, the participants had their height, weight, and waist circumference measured.

Participants were asked to wear their bunker gear issued to them by the City of Fargo/Fargo Fire Department while performing CPR and completing the graded exercise test (GXT). Participants then performed five rounds of CPR on a QCPR Resusci Anne (Laerdal Medical AS, Stavanger, Norway), which is high-fidelity equipment that can objectively capture CPR skills. Participants then participated in a warm-up consisting of: two minutes of walking on a treadmill at a comfortable pace with no incline. Immediately following the warm-up, participants completed the GXT until the participant reached volitional fatigue. Immediately following the GXT, participants were asked to perform five additional rounds of CPR.

3.5. Measures

3.5.1. ActiGraph GT3X+ Accelerometer

Each participant wore the GT3X+ acclerometer on the right hip via an adjustable, elastic waistband to objectively measure PA levels (Troiano et al., 2014). The participant wore the GT3X+ accelerometer during waking hours except for water based activities. Participants wore the GT3X+ accelerometers during sleeping hours for their on-duty shifts to capture PA if they received emergency calls during the night. During off-duty nights, however, the participants removed the accelerometer because they typically did not have their sleep disrupted to perform PA. The GT3X+ accelerometer tracked the PA intensity levels for both on- and off-duty days for the participants. The GT3X+ acclereomter was worn for a typical nine-day tour according to the Fargo Fire Department, which consisted of: 24 hours on-duty, 24 hours off-duty, 24 hours on-duty, 24 hours off-duty, 24 hours on-duty, and finally four days off-duty.

There were several methodological condiserations for the GT3X+ accelerometer. The epoch duartion was set at 60 second epochs (Freedson et al., 1998). Additionally the participant must have woren the GT3X+ for at least four days with a total of at least 10 hours of wear time per day (Aadland et al., 2015; Matthews et al., 2002; Matthews et al., 2012). In order to classify

PA intenstiy levels, Freedson's (Freedson et al., 1998) cutpoints were used along with Choi's non-wear time algorithm (Choi et al., 2011).

3.5.2. Sleep Log

Participants completed a sleep log for their on- and off-duty days. For on-duty days, participants were asked to log when they went to bed and wake-up, but they were asked to keep their accelerometer while they are sleeping. During off-duty days, participants logged when they went to bed at night and removed their acclerometer. Additionally, participants logged when they woke up in the morning and placed the accelerometer on their hip.

3.5.3. International Physical Activity Questionnaire

Participants completed the IPAQ when they reported to the HPL for the data collection session. The IPAQ was used to subjectively measure PA intensity levels across five domains. The domains included: job-related, tranportaion, work, leaisure-time, and time spent sitting (Craig et al., 2003). The previously mentioned domains were essential for understanding daily PA patterns which participants typically engaged in and subjectively reported.

3.5.4. Demographic Information

Each participant self-reported their demographic information. Participants' reported their age in years. Evaluation of education level was assessed by reporting the highest level completed ranging from some high school to post-graduate degree. The age range for participants is 20-55 years, in an effort to understand firefighters career standing based on their rank and number of years on the job. In order to examine previous medical emergency tasks, participants were asked serveral questions regarding their certification and how they were trained for CPR. Additionally, participants were asked how many times, if any, they had performed CPR and what the outcome was for the patient(s). The CPR survaillence questions were imperative to the study as quality of CPR was a variable of interest. Finally, firefighters are responsible for protecting the infrustructure of the city; thus firefighters have special certifications enabling them to perform specific tasks. Participants were asked to report all of their certifcaitons and current fire fighter classification.

3.5.5. Anthropometric Measures

Height was measured in centimeters (cm) using a stadiometer (Seco Corp, Model 213, Hamburg, Germany). Weight was measured in kilograms (kg) using a digital scale (Denver Instruments, Model DA 150, Bohemia, New York). To ensure reliability, height and weight was measured twice, and if the two measurements differed by more than 1 cm or 1 kg, respectively, a third measurement was taken. The two closest measurements were averaged and used to calculate body mass index (BMI). BMI was calculated by kg/m^2. The World Health Organization standards for BMI was used to categorize participants as underweight (<18.5), normal weight (18.5-<25), overweight (25-<30), and obese (≥30) (WHO, 1995). Each fire fighter had his waist circumference (WC) measured using a spring-loaded nonstretchable tape measure. WC was measured at the midpoint between the lower boarder of the rib cage and the iliac crest (WHO, 2000). Firefighters were considered obese if their WC is >102 cm. (WHO, 2000; Jitnarin, 2014).

3.5.6. CPR

Participants performed standard CPR as directed by the American Heart Association before and immediately after the GTX. The participants were fitted with a mouthpiece that was attached to the Parvo metabolic cart (ParvoMedics Inc., Logan, UT, USA) for all rounds of CPR. The five rounds of CPR were performed according to the current AHA guidelines (Klienman et al., 2015) on the QCPR Resusci Anne manikin (Laerdal Medical AS, Stavanger, Norway), which provided raw data indicating the quality of CPR performed. The raw data consisted of: the mean compression rate, the number of compressions that were fully released, the mean depth of compressions, the number of compressions that met the depth requirement, the compression/depth ratio, the compression interruption, the ventilation rate per minute, and the ventilation volume. All of the raw data was used to give a percentage (0-100%) for overall quality of CPR.

3.5.7. CRF

Open circuit spirometry (Parvo Medics, Logan, UT, USA) was used during CPR and GXT testing, which measured O_2 consumption (VO_2) and carbon dioxide production (VCO_2). Subjects wore a nose clip and breathe through a two-way rebreathing valve with one end connected to the participant and the other to the metabolic cart. Telemetry heart rate monitor values were recorded (Polar Electro Inc, Lake Success, NY, USA) and all data were averaged into 15-second time intervals. Filter replacement and calibration was performed between tests according to the manufacturer's guidelines.

The participants performed a GXT on a Trackmaster TMX425C treadmill (Full Vision, Inc., Newton, KS) following the Balke-Ware protocol (Balke & Ware, 1959). Participants started the GXT at 3.3 mph with 0% incline while each successive one-minute stage increases 1% gradient with the speed remaining constant. The participants continued the GXT until they reached volitional fatigue. The square-wave verification bout was used to corroborate participants' $VO_{2\ max}$ measured during the GXT. Once the participants reached volitional fatigue, they were brought down to 50% of their equivalent vertical speed workload and remained at this stage for three minutes (Kirkeberg, Dalleck, Kamphoff, & Pettitt, 2013; Rossiter, Kowalchuk, & Whipp, 2011). After the three minutes, the workload increased to 65-80% of their initial workload. The duration of the final stage was another two to three minutes. The final stage verified if participants truly reached their $VO_{2\ max}$.

3.6. Statistical Analysis

All statistical analyses were conducted using SPSS (version 24). Statistical significance was set at the 0.05 level of confidence. The following analyses were used to answer the research questions:

1. Do physical activity intensity levels, body mass index, and/or waist circumference predict cardiorespiratory fitness in career firefighters?
   a. A stepwise linear regression model was conducted using physical activity intensity, BMI, and WC as predictor variables for CRF.
2. How do physical activity intensities differ between on- and off-duty days in career firefighters?
   a. Dependent t-tests were conducted to assess differences in physical activity intensities between on- and off-duty days.
   b. Independent t-tests were conducted between firefighters who attained 30 minutes or more of MVPA and those who did not to compare differences in physical activity intensities.

3.7. Conclusion

Currently, there is a growing concern for the rise in obesity levels in firefighters (Clark et al., 2002; Poston et al., 2011). The rise in obesity has also lead to an increase in negative health outcomes such as: increased blood pressure, increased cholesterol, and decreased CRF (Clark et al., 2002; Soteriades et al., 2008). Thus, sudden cardiac death continues to be the number one cause of death in firefighters (Fahy, 2012; Fahy et al., 2016). After examining the current PA and CRF levels, this could give further insight to the high prevalence of obesity in firefighters.

According to the NFPA, the number of medical emergencies firefighters responds to supersede the number of fire calls. Therefore, firefighters need to be able to adequately perform medical emergency tasks. This study will investigate the relationship of objectively measured PA and obesity on CRF. In addition, the study will also investigate how physically active firefighters are on- and off-duty.

CHAPTER 4. THE PREDICTION OF PHYSICAL ACTIVITY, BODY MASS INDEX, AND WAIST CIRCUMFERENCE TO CARDIORESPIRATORY FITNESS IN CAREER FIREFIGHTERS

4.1. Abstract

Purpose: The inactivity and obesity levels in US firefighters are devastating to firefighters' ability to engage in physiologically demanding jobs expectations. The increased body weight combined with excessive sedentary behavior increases firefighters' susceptibility to cardiovascular disease. Physical activity (PA) has been shown to decrease obesity as well as improve cardiorespiratory fitness (CRF). Thus, the present study evaluated the association of objectively measured PA and obesity to CRF. **Methods:** Twenty-nine career firefighters participated in a cross-sectional study design. Accelerometers assessed PA intensities and step count. Obesity was classified using body mass index (BMI) and waist circumference (WC). Each participant completed a stage-graded exercise test with submaximal square-wave verification bout to determine maximal oxygen uptake (VO_{2max}). VO_{2max} was also estimated using self-reported physical activity rating (PA-R) and a non-exercise regression equation. Linear regression models examined if PA intensities, step-count, PA-R, BMI and WC predicted VO_{2max}. **Results:** Firefighters spent roughly 61% of their waking hours in sedentary activity, 35.4% in light phyical activity, and only 3.6% in moderate-to-vigorous physical activity. Two linear regression models were used to investigate whether PA intensities, step count, PA-R, BMI, or WC were more predictive of "true" VO_{2max}. Vigorous physical activity (VPA) was predictive of VO_{2max} (P <0.01). Additionally, when BMI and WC were added, only WC was predictive of "true" VO_{2max} (P<0.01). **Conclusion:** VPA was predictive of "true" VO_{2max}, however, when WC was added to the model, WC was the only predictive variable. Fire departments should be

cognizent of ways to improve PA levels and, in turn, decrease excess weight gain to maintain CRF to adequately perform job-specific tasks.

4.2. Introduction

Firefighters in the United States have suboptimal fitness levels and excess body weight, which is detrimental to the high-energy job demands (Elsner et al., 2008; Kales et al., 1999; Lemon et al., 1997; Smith et al., 1996; Durand et al., 2011; Baur et al., 2012a). The deleterious fitness levels and elevated body weight can cause firefighters to exceed their physiological limitations while engaging in firefighting tasks (Elsner et al., 2008; Soteriades et al., 2011; Holmer et al., 2007; von Heimburg et al., 2006). The majority of a firefighter's day is spent in sedentary or light activities, which does not adequately prepare them for the more rigorous tasks that can occur during their shift (FEMA, 2009). The rapid change and longer duration of elevated heart rate potentially leads to negative cardiovascular events. During the past 38 years, the number one cause of death in firefighters was sudden cardiac death (Fahye, 2016). Further cardiovascular events, such as heart attacks, are one of the main causes of early retirement. Therefore, the United States Fire Service's as well as the National Fire Protection Association's initiative is to increase physical activity (PA) to subsequently increase cardiorespiratory fitness (CRF) (NFPA, 2007). During peak levels of maximal exertion, it is imperative that firefighters have high aerobic capacity (Elsner et al., 2008); firefighting tasks are often performed at 60-80% of maximum CRF (Lemon et al., 1997; Elsner et al., 2008; Holmer et al., 2007; von Heimburg et al., 2006). Firefighters who have increased CRF are able to perform at higher capacities which offers resistance to negative effects on the cardiopulmonary system (Elsner et al., 2008; Holmer et al., 2007; von Heimburg et al., 2006).

The National Fire Protection Association (NFPA) established code 1582: *Standard on Health-related Fitness Program in Firefighters* to promote increased CRF levels with a minimum VO_{2max} of 42 mL · kg^{-1} · min^{-1} (NFPA, 2007). Although the code was developed to improve the health and wellness of firefighters, the NFPA is not a governing body for U.S. firefighters; therefore, administrators within a fire engine company (i.e., fire chief or assistant chiefs) choose whether they want to enforce this standard. Recently the NFPA, reported only 27% of U.S. fire departments have mandated health and wellness guidelines (NFPA, 2016). Because there is no governing body, department administrators administer their own fitness and health screenings without a standard for CRF or PA requirements. Thus, the only guidelines available for these occupational athletes are from the CDC and ACSM of 150 minutes of moderate-to-vigorous physical activity per week, which does not account for the physical performance of an athlete (Garber et al., 2011). At present, no published literature has established minimum PA levels for firefighters to attain the NFPA CRF guidelines.

Self-reported measures have demonstrated the majority of firefighters are not attaining the weekly recommendation of 150 minutes of moderate-to-vigorous physical activity (MVPA) (Baur et al., 2012; Durand et al., 2011). The specific survey used assessed frequency, duration, and intensity of exercise; therefore, the survey was not able to assess all aspects of MVPA through the day. The survey did not assess PA for occupational, transportation or household activities all of which have the potential to contribute overall MVPA. It is imperative for future studies to examine PA levels using objective measurements during a variety of activities including on- and off-duty scenarios.

In addition to physical inactivity, the elevated prevalence of overweight and obese firefighters has also been associated with decreased CRF (Clark et al., 2002). According to body mass index (BMI) assessments, roughly 75% of all firefighters are overweight with 40% classified as obese (Baur et al., 2012; Clark et al., 2002; Durand et al., 2011; Soteriades et al., 2008; Tsismenakis et al., 2009; Poston et al., 2011). Additionally, a population-based cohort study determined career firefighters were more likely to be overweight or obese than the general U.S. population (Poston et al., 2011). Furthermore, it is essential to note that obesity prevalence was increased when firefighters were assessed using body fat rather than BMI (Poston et al., 2011).

As a result of increased obesity levels, firefighters also experience a decline in their fitness levels resulting in a decreased ability to safely and efficiently perform job-specific tasks (Baur et al., 2012; Durand et al., 2011). Studies have demonstrated that roughly 25-60% of firefighters do not meet the NFPA minimum guidelines, which suggests these firefighters would not be able to successfully engage in on-duty jobs (Baur et al., 2012; Donovan et al., 2009; Durand et al., 2011). Furthermore, firefighters who have superior fitness levels have been shown to complete job-specific tasks faster and more efficiently than their less fit cohorts (Elsner et al., 2008). Thus, more emphasis needs to be placed on improved CRF levels and increasing the amount of PA to protect each firefighter.

Currently, there is negligible literature examining the relationship between PA and CRF in career firefighters (Durand et al., 2011; Baur et al., 2012a). There is evidence, however, to suggest firefighters with higher CRF levels also engage in frequent, longer, and intense bouts of exercise (Durand et al., 2011; Baur et al., 2012a). There is a limitation to literature though as the current research has only used subjective rather than objective measures of PA. Thus, there remains a gap in the literature to objectively examine PA intensities during on- and off-duty scenarios. As a result, it remains unclear how PA during on- and off-duty events effects CRF in firefighters. Therefore, the purpose of the present study was to investigate the association of objectively measured PA and obesity levels on CRF in firefighters.

4.3. Methods

4.3.1. Participants

A convenience sample of 30 active, structural, career, male firefighters were recruited from a mid-sized, Midwestern, city. Participants were excluded from the study if: 1) they had musculoskeletal injuries precluding the firefighter from active, on-duty tasks; 2) previous medical concerns from prior graded exercise tests (GXT); or 3) inability to perform treadmill walking with issued turnout gear.

Before any data were collected, all participants read and signed an Institutional Review Board-approved written informed consent. Participants were informed all of their data collected in the study would remain confidential and would not become part of their health records within the fire department. One participant did not complete the study protocol; thus, he was removed from the data analysis, leaving a final sample of 29 participants.

4.3.2. Study Design

The participants engaged in a cross-sectional study design where demographics, anthropometric measures, PA levels, and CRF were assessed. Demographic information such as age and number of years at the fire station were obtained through a self-reported survey. Height was assessed using a portable stadiometer (Seco Corp, Model 213, Hamburg, Germany); weight was measured using a digital scale (Denver Instruments, Model DA 150, Bohemia, New York). Firefighters' height and weight were measured without shoes and wearing light clothes as well as with their fire department-issued pants and boots from their turnout gear. Body mass index (BMI) was defined as weight in kilograms divided by square of height in meters using height and weight without turnout gear. Additionally, waist circumference (WC) was measured using a spring-loaded nonstrechable tape measure following current National Institutes of Health obesity guidelines. According to the recommendations of Jitnarin et al. (2014), firefighters were classifed as obese if BMI ≥ 30 kg/m^2 and WC >102 cm.

4.3.2.1. Assessment of Physical Activity

Firefighters wore an ActiGraph GT3X+ accelerometer on their right hip via an elastic waist band for the duration of one tour (9 days) which consisted of: 24 hours on-duty, 24 hours off-duty, 24 hours on-duty, 24 hours off-duty, 24 hours on-duty, and finally four days off-duty. The firefighters wore the accelerometer during waking hours except for water-based activities. The epoch duartion was set at 60 second epochs (Freedson, 1998). Firefighters had to wear the GT3X+ for at least four days with a total of at least 10 hours of wear time per day to be included in the analysis. In order to classify PA intensity levels, Freedson's (Freedson, 1998) cutpoints were used along with Choi's non-wear time algorithm (Choi et al., 2011).

4.3.2.2. Assessment of Cardiorespiratory Fitness

The GXT was conducted on a Trackmaster TMX425C treadmill (Full Vision, Inc., Newton, KS). A metabolic analyzer (Parvomedics, Logan, UT, USA) was used during the testing. Telemetry heart-rate-monitor values also were recorded simultaneously (Polar Electro Inc., Lake Success, NY, USA), and all data were evaluated using 15-s sampling rate. Firefighters wore their pants and boots from their turnout gear while engaging in the GXT. The Balke-Ware protocol was used for the GXT (Balke-Ware, 1957). Briefly, during the Balke-Ware protocol the firefighters start to exercise at 5.5 km/h, 0% gradient with an increase to 2% gradient after the first minute then a 1% gradient increase for every successive minute. After the individual reached volitional fatigue, a 3-min active recovery at 50% of VO_{2max} was administered after the GXT. Subsequently, an exhastive square-wave bout at two stages below the last stage attained during the incremental test was used to verify VO_{2max} (Pettitt, 2013; Kirkeberg, 2011; Sedgema, 2013). Prior to participants completing the GXT, participants completed a self-reported physical activity rating (PA-R) scale from 1-15, used in current literature to accomaodate more robost levels of physical activity (Dicks et al., 2016, Jamnick et al., 2016), modifed from George et al (1997), to estimate the firefighters relative VO_{2max}. Each firefighter's relative VO_{2max} was estimated using a non-exercising regression equation (Jackson et al. 1990), where VO_{2max} was expressed in milliliters per kilogram per minute, body mass (BM) was in kilograms.

4.4. Statistical Analyses

Demographic and anthropometric measures were described using means and standard deviations. Initial steps were taken to ensure normaility of data before conducting statistical analysis. Normality of data was confirmed with visual representation from Q-Q plots. To examine mean differences between predicted and "true" VO_{2max}, dependent t-tests were performed. Pearson's product-moment correlations were used to assess the association between PA intensity levels, "true" VO_{2max} and predicted VO_{2max}. Two stepwise linear regressions were conducted both using "true" VO_{2max} as the dependent varible. One of the regressions included sedentary behavior, light physical activity (LPA), moderate physical activity (MPA), vigorous physical activity (VPA), moderate-to-vigorous physical activity (MVPA), step count, and PA-R as independent variables while the other model included WC and BMI. An alpha level of 0.05 was used to determine statistical significance. All statistical analyses were performed using IBM SPSS 24 software (IMB Corp., Armonk, NY).

4.4. Results

A total of 29 firefighters completed the study. According to the WC and BMI recommendations (Jitnarin et al., 2014), only five firefighters were classified as obese. Comparitively, using the World Health Organization BMI categorization, none were normal weight, 20 were overweight, and 9 were obese. Almost half (48%) met either the ACSM PA or the NFPA CRF guidelines, but only about a quarter (24%) of the participants met both the

ACSM and NFPA guidelines. More specifically in regards to PA, firefighters spent roughly 61% of their waking hours in sedentary activity, 35.4% in LPA, and only 3.6% in MVPA (Figure 1). Overall, the firefighters barely met the ACSM guidelines with an average MVPA per day of 30.05 minutes, but did not attain the NFPA CRF recommendation with an average of 40.82 ± 6.95 mL · kg^{-1} · min^{-1}. Participant demographic information can be found in Table 12.

Table 12

Participant Characteristics

Characteristics	Mean ± SD
Height with gear (cm)	184.64 ± 6.76
Weight with gear (kg)	101.27 ± 11.21
Height (cm)	180.74 ± 6.80
Weight (kg)	94.70 ± 10.65
BMI	28.97 ± 2.52
WC (cm)	96.48 ± 7.95
Age (yr)	34.45 ± 7.15
Years at the Fire Department (yr)	7.01 ± 5.97

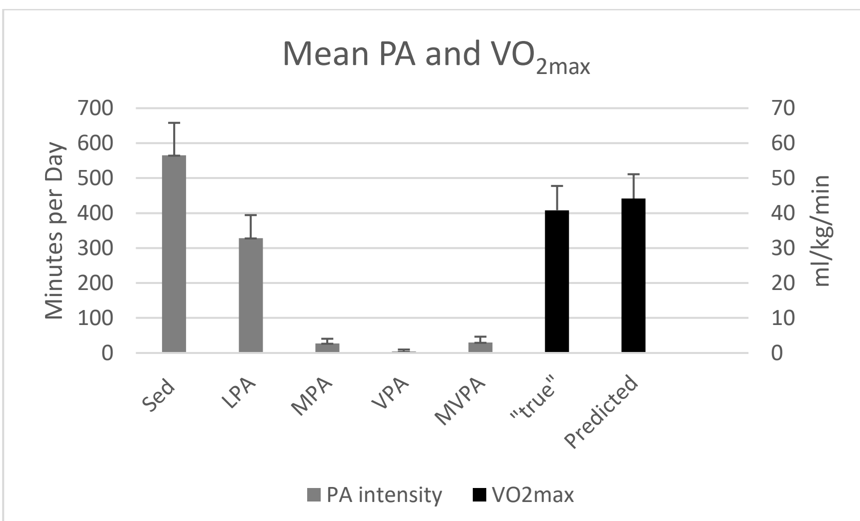

Figure 1. Mean PA intensities and VO2max of the participants

VO_2 values from the GXT and the square wave verification bout were 40.82 ± 6.95 and 39.25 ± 6.85 mL · kg^{-1} · min^{-1} respectively, (ICC=0.94, SEM=1.57 mL · kg^{-1} · min^{-1}, CV=0.43%) with the highest value used to identify "true" VO_{2max}. On average, the firefighters had a higher predicted than “true” VO_{2max}, which was statistically significant ($p = 0.017$) with a medium effect size ($d = 0.48$). There was a significant correlation between vigorous physical activity (VPA) and “true” VO_{2max} ($p = 0.009$). Refer to Table 13 for additional correlations between PA intensity levels and VO_{2max}.

Table 14 summarizes the stepwise linear regression with “true” VO_{2max} as the dependent variable and sedentary behavior, light physical activity (LPA), moderate physical activity (MPA), vigorous physical activity (VPA), step count, and PA-R as independent variables ($R^2 = 0.23$). When BMI and WC were added as additional independent variables, R-squared increased ($R^2 = 0.30$) (Table 15). The two models were used to investigate whether PA intensity, step count, PA-R, BMI, or WC were more predictive of “true” VO_{2max}. VPA was predictive of VO_{2max} ($F(1,27) = 7.89$, $R^2 = 0.23$, $p < 0.01$). Additionally, when BMI and WC were added, only WC was predictive of "true" VO_{2max} ($F(1,27) = 11.76$, $R^2 = 0.30$, $p<0.01$). VPA predicted 23% of the variance in “true” VO_{2max} ($p<0.01$); WC predicted 30% of the variance in “true” VO_{2max} ($p<0.01$).

Table 13

Physical Activity, VO_{2max}, and Body Composition Correlation Matrix (N=29)

Variables	1	2	3	4	5	6	7	8
1. Sedentary Average	--	-.62***	-.16	-.22	-.19	-.12	.26	-.04
2. LPA Average		--	.18	.12	.26	.08	-.14	.21
3. MPA Average			--	.29	0.33	.12	-.33	-.12
4. VPA Average				--	.48***	.36	-.42*	-.36
5. "True" VO_{2max}					--	.48**	-.55**	-.531**
6. Predicted VO_{2max}						--	-.81***	-.77***
7. WC							--	.693***
8. BMI								--

***Correlation is significant at the $p < 0.001$ level
** Correlation is significant at the $p < 0.01$ level
* Correlation is significant at the $p < 0.05$ level

Table 14

Stepwise Regression Model

Variable	B	SEB	ß
Constant	38.611***	1.399	
VPA	0.560***	.200	0.476

*p <0.05 **p<0.01 ***p<0.001

Table 15

Stepwise Regression Model

Variable	B	SEB	ß
Constant	87.313***	13.601	
WC	-0.482***	.141	-0.551

*p <0.05 **p<0.01 ***p<0.001

4.5. Discussion

The present study adds to the body of literature suggesting there is a strong correlation with increased PA intensities and higher aerobic capacities (Durand et al., 2011). The correlation, however, was only statistically significant with VPA and "true" VO_{2max}. On average, the firefighters barely met the minimum recommendation of 30 minutes/day of MVPA recommended by the CDC and ACSM. Unfortunately, the firefighters, on average, did not obtain the NFPA CRF levels, even though they were meeting the PA guidelines.

Contrary to common wisdom in the general population, the results of this study suggests firefighters are not engaging in long durations of MVPA. Approximately 50% of the firefighters in the current study did not meet the minimum PA guideline of 30 min of MVPA/day. Comparably, Durand et al. (2011) used a self-report measure for exercise resulting in < 80% of firefighters engaging in at least 150 min of MVPA on a weekly basis. It is important to note that social desirability bias was not a factor in the study as there was no bias toward negative results. Although overall MVPA was low, VPA was a statistically significant predictor of CRF. Durand et al. (2011) also demonstrated increased intensities were associated with higher CRF levels in firefighters. Thus, both studies demonstrate the importance of a variety of research methods in order to investigate the role of PA for firefighters.

In the current study, firefighters were not only inactive, but also were overweight and obese resulting in 55% of firefighters not meeting the NFPA CRF guidelines. Additionally, the BMI measurements indicated that all of the firefighters were considered either overweight or obese. The prevalence of overweight and obese firefighters in the current study were higher than previous studies of approximately 75% considered overweight or obese (Baur et al., 2011; Clark et al., 2002; Durand et al., 2011; Poston et al., 2011; Soteriades et al., 2008; Tsismenakis et al., 2009). Additionally, the results from the current study revealed WC is an inverse predictor of CRF. Similar studies assessing weight status using BMI have consistent results with an inverse association between BMI and CRF (Baur et al, 2012; Durand et al, 2011; Poston et al, 2011).

There is an increasing consensus across all studies that 25-50% of firefighters are not attaining CRF level to properly prepare them for physiologically demanding tasks (Baur et al, 2011; Baur et al, 2012; Donovan et al, 2009; Durand et al, 2011; Poplin et al, 2013). In the current study, a little more than half of the firefighters did not meet the NFPA guidelines suggesting they would not be aerobically fit for on the job tasks. It should also be noted that the NFPA guidelines may not account for department-specific proficiencies necessary to perform skills specific to each city's infrastructure. For example, there is vast differences in the infrastructure in a large metropolitan city compared to a mid-sized, Midwestern city.

There were several limitations for this study. First, firefighters did not wear the accelerometer for the full 24-hour off-duty days. Firefighters removed the accelerometer when they went to bed during off-duty days. Thus, only data worn during waking hours for both on- and off-duty shifts was used. However, the firefighters wore the accelerometer for seven days with roughly 15 hours per day, which exceeds the four-day requirement for accelerometer validity.

There were a couple of additional limitations to the present study. The firefighters did not wear their full turnout gear when the engaged in the VO_{2max} test. While we acknowledge it would have been ideal to assess VO_{2max} in firefighters in full gear, we also recognize the majority of calls are for medical or false alarms rather than true structural fire alarms and typically do not dress with full gear for these types of calls (NFPA Statistics, 2015). The firefighters in the current study wore their fire departments issued bunker pants and boots. The firefighters were recruited from the same fire department, so the results of this study might not be transferable to other departments.

Our study had several important strengths. First, this is one of the first studies to objectively measure PA in structural firefighters. Second, we were able to conduct a VO_{2max} test using a protocol that simulated on-the-job ambulatory movement (i.e. not running), and the methodology incorporated VO_2 data from a metabolic analyzer as opposed to estimating via a metabolic equation. Third, although our sample was small, the results of our study were still consistent with larger epidemiological studies (Baur et al., 2011; Baur et al., 2011; Durand, et al., 2011).

In conclusion, we found VPA and WC are predictors of CRF. The present study supports the need for firefighters to increase time spent in MVPA and weight maintenance to sustain a higher standard of CRF. Future research could include larger sample sizes from different geographic areas to better understand the role of objectively measured PA data on CRF in structural, career firefighters. It is imperative that all members of a fire department emphasize the importance of cultivating an environment where improved health and wellness is essential for firefighters to adequately perform their physiologically demanding tasks.

CHAPTER 5. FIREFIGHTERS ARE MORE PHYSICALLY ACTIVE ON-DUTY COMPARED TO OFF-DUTY

5.1. Abstract

Physical inactivity coupled with increasing obesity levels in firefighters play a key role in aggregated cardiovascular events. Currently, career firefighters are more obese than the general population, however, there is no objective measurements to compare physical activity (PA) levels between the two populations. **Purpose:** To objectively measure PA for firefighters while on- and off-duty in order to have a clearer understanding of their overall PA level. **Methods:** Twenty-nine career firefighters participated in a non-experimental, within-subjects design. Firefighters wore an accelerometer to asses PA intensities and step-count. Obesity was classified using body mass index. Dependent t-tests were used to examine mean differences in PA intensities between on- and off-duty days. Pearson product-moment correlations were used to assess the assocation between PA intensities for both on and off-duty days. Independent t-tests examined differences in PA intensities and step counts between firefighters who met and did not meet the American Colleges of Sports Medicine's (ACSM) PA guidelines. **Results:** According to the World Health Organization BMI categorization, 20 firefighters were overweight, 9 were obese, and none were normal weight. After conducting a dependent t-test, only LPA was statistically significant (P=0.026) for on- and off-duty days with a medium effect size (d=0.47). When examining associations between on- and off-duty days, each intensity was significantly associated with the corresponding intensity except for vigorous physical activity. More firefighters met the ACSM PA guidelines during on- than off-duty days. **Conclusion:** As the results demonstrated, there is a dire need for increased PA levels in firefighters while on- and off-duty.

5.2. Introduction

Physical inactivity is currently the fourth leading cause of death worldwide, which classifies the condition as a global pandemic (Kohl et al., 2012; Anderson et al., 2016). As the general public attempts to deal with a rising obesity epidemic, firefighters are also concerned with increased obesity prevalence, as the excessive weight in firefighters predisposes them to cardiovascular events while performing necessary job duties (Poston et al., 2011). In the past 38 years, the number one contributor to on-duty fire fighter fatalities was sudden cardiac death (Fahy, 2016). Although the overall number of on-duty deaths has declined, the risk of a cardiac event still remains relatively high.

The National Fire Protection Association (NFPA) developed codes 1582: *Standard on Health-related Fitness Programs for Firefighters* and 1583: *Standard on Health-Related Fitness Programs for Fire Department Members* to combat the high rates of physical inactivity and obesity in firefighters across the country (NFPA 1582, 2007; NFPA 1583, 2013; Soteriades et al., 2008; Tsismenakis et al., 2009; Poston et al., 2011; Durand et al., 2011; Baur et al., 2011). Although the codes were implemented into the U.S. Fire Service, each departments' adherence to these codes are voluntary; therefore, it is the discretion of the administrative officials at individual departments if they will comply with the proposed standard. Currently in the U.S., roughly one quarter of fire departments employ firefighters who engage in a basic fitness and health program. Unfortunately, this number has decreased 3% over the past eight years (NFPA Needs Assessment, 2015).

The development of health and wellness programs requires a considerable amount of time and financial resources. In 2011-2014, only 1% off all funding from the Federal Emergency Management Agency (FEMA) was allocated to improving health and wellness for firefighters (NFPA Needs Assessment, 2015). Therefore, firefighters may not receive external pressure from department administrators to maintain PA levels necessary to sustain the intense physiological demands.

Few studies have investigated PA levels in firefighters to better understand how they can maintain their cardiorespiratory fitness levels (Durand et al., 2011). One study surveyed the frequency, intensity, and duration of PA of 527 career firefighters from the Midwest. Among those firefighters, roughly 25% subjectively reported they engaged in 150 minutes of PA per week as, which meets the American College of Sports Medicine's PA guidelines (Garber et al., 2011).

The increased obesity levels as well as an augmented risk of a cardiovascular event while engaging in job-specific tasks enhances the need for further investigation for PA in firefighters. Specifically, assessing PA levels while on-duty compared to off-duty will allow administrative personnel to focus their efforts to encourage immediate lifestyle changes. The purpose of this study was to objectively measure PA for firefighters while on- and off-duty to have a clearer understanding of their overall PA level. We hypothesized firefighters would have increased PA levels during their on-duty days compared to off-duty days.

5.3. Methods

Thirty active, structural, career firefighters were recruited from one Midwestern fire department. Participants were excluded from the study if they had musculoskeletal injuries precluding the firefighter from active, on-duty tasks. The affiliate university's Institutional Review Board approved the study; written informed consent was obtained from each participant.

PA and anthropometric measures were assessed in a non-experimental, within-subjects design. Height was assessed using a portable stadiometer (Seco Corp, Model 213, Hamburg, Germany); weight was measured using a digital scale (Denver Instruments, Model DA 150, Bohemia, New York). Body mass index (BMI) was defined as weight in kilograms divided by square of height in meters.

Firefighters wore an ActiGraph GT3X+ (ActiGraph Corp, Pensacola FL) accelerometer on their right hip via an elastic waist band for the duration of one tour which consisted of: 24 hours on-duty, 24 hours off-duty, 24 hours on-duty, 24 hours off-duty, 24 hours on-duty, and finally four days off-duty (9 days total). The GT3X+ accelerometer uses microelectricomechanical accelerometers that take raw electrical signals and translates them, using proprietary algorithms, into values of movement. These data points are used to produce estimates of activity duration and intensity. Intensity was classified as sedentary, light physical activity (LPA), moderate physical activity (MPA), vigorous physical activity (VPA), and moderate-to-vigorous physical activity (MVPA). The firefighters wore the accelerometer during waking hours except for water based activities. Firefighters completed a sleep log detailing when they woke up in the morning to wear the accelerometer and when they removed the accelerometer to go to bed at night. Firefighters had to wear the GT3X+ for at least four days with a total of at least 10 hours of wear time per day to be included in the analysis. The epoch duartion was set at 60 second epochs (Freedson, 1998). In order to classify PA intensity levels, Freedson's (Freedson, 1998) cutpoints were used along with Choi's non-wear time algorithm (Choi, 2011). Tudor-Locke and Bassett (2004) step count indices were also used to categorically classify healthy adults. There are five categorical groups: 1) "sedentary behavior" is <5000 steps/day; 2) "low activity" without an exercise regimine is 5000-7499 steps/day; 3) "somewhat active" with some intense activities including occupational demands is 7500-9999 steps/day; 4) to be classified as "active" is ≥10000 steps/day; and 5) "highly active" is >12500 steps/day.

Demographic characteristics were described using mean (SD) and frequency. Dependent t-tests were used to examine mean differences in PA intensities between on- and off-duty days. Pearson product-moment correlations were used to assess the assocation between PA intensities for both on and off-duty days. In order to explore differences in PA intensities and step counts between firefighters who met and did not meet the ACSM guidelines, independent t-tests were calcuated to determine statsitcal significance. Analyses were performed in SPSS 24 (IMB Corp., Armonk, NY). The level of significance was set a *P* <0.05.

5.4. Results

A total of 29 firefighters (age: 34.45±7.15 yr; BMI: 28.97±2.52 kg/m^2) completed all aspects of the study. According to the World Health Organization BMI categorization, 20 firefighters were overweight, 9 were obese, and none were normal weight. Mean (SD) accelerometer wear time was 15.8 (1) hours for on-duty days and 15.0 (1.3) hours for off-duty days. There was a statistically significant difference for total wear time of the accelerometer between on- and off-duty days with a mean difference of 51 minutes (*P*<0.05). After conducting a dependent t-test, only LPA was statistically significant (*P*=0.026) for on- and off-duty days with a medium effect size (d=0.47) (Table 16). Although MVPA for on- and off-duty days was not statistically signficant (*P*=0.055), there was still a moderate effect size (d=0.40). Additionally, 45% of participants were considered “active or highly active” for on-duty shifts following the step count indices compared to only 14% during off-duty shifts (Table 17).

Table 16

Dependent t-test values and effect sizes (d) for PA intensities

PA Intensity	t	df	p	On-duty M	On-duty SD	Off-duty M	Off-duty SD	d
Sedentary	0.46	28	0.650	563.31	63.24	555.25	111.10	0.09
LPA	2.35	28	0.026	351.11	59.90	315.83	86.90	0.47
MPA	1.72	28	0.097	30.50	17.48	24.66	14.94	0.36
VPA	1.232	28	0.228	5.02	7.41	3.16	6.65	0.26
MVPA	2.00	28	0.055	35.51	19.22	27.82	18.91	0.40

Mean (M) and SD are listed in minutes.

Table 17

Step Count Categorization Frequency

Step Count Categorization	On-duty Frequency (%)	Off-duty Frequency (%)
< 5000	1 (3.4)	4 (13.8)
5000-7499	3 (10.3)	10 (34.5)
7500-9999	12 (41.4)	11 (37.9)
> 10000	9 (31.0)	2 (6.9)
>12500	4 (13.8)	2 (6.9)

Refer to Table 18 for correlations between on- and off-duty days for average PA intensities and step count. When examining associations between on- and off-duty days, each intensity was significantly associated with the corresponding intensity except for VPA. Additionally, there was no significant association between average step count for on- and off-duty days (P>0.05).

More firefighters met the ACSM PA guidelines during on- than off-duty days. There was a significant difference between firefighters who met compared to those who did not meet the PA guidelines for MPA, VPA, MVPA, and during on-duty (Table 19) as well as off-duty days (Table 20). There was, however, a trend toward significance for LPA between those who met and did not meet the guidelines during on-duty shifts (P=0.54, d=0.77).

Table 18

On- and Off-Duty Physical Activity Correlation Matrix (N=29)

Variables	1	2	3	4	5	6	7	8	9	10	11	12
1. On Sedentary Average	--	-.53***	-.10	-.48**	-.28	-.23	.53**	-.40*	-.12	-.20	-.39	-.25
2. On LPA Average		--	.11	.21	.18	.28	-.20	.44*	.11	.16	.15	.27
3. On MPA Average			--	.04	.92***	.52**	.16	-.06	.37*	.29	.40	.16
4. On VPA Average				--	.42*	.47*	-.19	.07	.03	.33	.14	.11
5. On MVPA Average					--	.66***	.07	-.03	.35	.39*	.41*	.19
6. On Steps Average						--	-.14	.19	.31	.46*	.40*	.36
7. Off Sedentary Average							--	-.71***	-.28	.00	-.22	-.44*
8. Off LPA Average								--	.25	-.06	.17	.57**
9. Off MPA Average									--	.45*	.95***	.80***
10. Off VPA Average										--	.70***	.60***
11. Off MVPA Average											--	.84***
12. Off Steps Average												--

*** Correlation is significant at the $p < 0.001$ level
** Correlation is significant at the $p < 0.01$ level
* Correlation is significant at the $p < 0.05$ level

Table 19

Independent samples t-test values and effect sizes (d) for on-duty PA intensities

PA Intensity	t	df	p	Met ACSM M	Met ACSM SD	Not Meet ACSM M	Not Meet ACSM SD	d
Sedentary	1.64	27	0.112	547.58	62.68	585.60	59.50	0.62
LPA	2.01	27	0.054	368.96	61.86	325.81	48.73	0.77
MPA	4.15	27	0.000	39.50	17.15	17.74	6.84	1.67
VPA	2.39	25.23	0.025	7.37	8.32	1.70	4.33	0.85
MVPA	5.32	27	0.000	46.87	16.70	19.44	7.35	2.13

Mean (M) and SD are listed in minutes. N=17 for meeting ACSM guidelines. N=12 for not meeting ACSM guidelines

Table 20

Independent samples t-test values and effect sizes (d) for off-duty PA intensities

PA Intensity	t	df	p	Met ACSM M	Met ACSM SD	Not Meet ACSM M	Not Meet ACSM SD	d
Sedentary	-0.25	27	0.980	554.46	101.95	555.61	117.53	-0.01
LPA	0.98	27	0.923	318.22	83.09	314.76	90.65	0.04
MPA	7.57	27	0.000	42.70	9.98	16.54	7.97	2.90
VPA	2.75	8.95	0.025	9.22	9.58	0.43	1.10	0.85
MVPA	9.19	27	0.000	51.92	11.93	16.97	8.23	1.29

Mean (M) and SD are listed in minutes. N=9 for meeting ACSM guidelines. N=20 for not meeting ACSM guidelines

5.5. Discussion

Firefighters were more physically active on-duty than off-duty with only a little over half of the firefighters meeting the ACSM PA guidelines while on-duty. There was a significant difference in average MPA, VPA, MPVA, and step count between those who met and did not meet the ACSM guidelines for both on- and off-duty days. Roughly 41% of firefighters had step counts similar to individuals who have physically active occupations while on-duty compared to 38% off-duty (Tudor-Locke & Bassett, 2004). Additionally, 45% of firefighters were classified as active or high active according to step counts for on-duty compared to 14% of firefighters when off-duty.

Adults spend the majority of their waking hours in an occupational environment; therefore, it is imperative to have a clearer understanding of occupational physical activity levels (Church et al., 2011). Thorp and colleagues (2012) issued office workers an accelerometer to be worn during working and non-working days. The results of the study demonstrated the individuals engaged in sedentary activity for roughly 77% of their 15.3-hour work days compared to 63% during non-work days. Comparatively, the firefighters in the current study engaged in sedentary activity for roughly 60% of their on-duty shift and 61% of their off-duty day. Additionally, the office workers only engaged in 1.9% of MVPA during the work day and 4.3 % of MVPA on non-working days. Even though the firefighters participated in more MVPA during on-duty days (3.7%) than off-duty days (3.1%), the total amount of MVPA is essentially similar to that of office workers.

Very little research has been conducted on people in various job settings. Although the comparison of firefighters to office workers may at first seem arbitrary, the results of the PA of firefighters is comparable to the subjects in the Thorpe study. Common logic would suggest office workers would have a high proportion of sedentary time. While the researchers of the current study report a large amount of sedentary time for firefighters, it should be highlighted that firefighters are expected to engage in physiologically demanding tasks with no advanced warning. The sudden shift in response is thought to activate the sympathetic nervous system causing a surge in the firefighter's heart rate (Barnard, 1975; Kourinka, 1981). The initial spike in heart rate remains in prolonged tachycardia throughout fire suppression tasks with transient ST-segment changes, which possibly indicates myocardial ischemia (AlZaiti, 2015; Barnard, 1975; Duncan 1979). These physiological derangements can lead to potential myocardial infarctions resulting in sudden cardiac death (Rubart, 2005). In order to alleviate the chance of a cardiovascular event, more research is needed to study the effects of individualized wellness or fitness programs that would emphasize the sudden burst of the sympathetic nervous system.

Not only are firefighters engaging in proportionally more sedentary activity, but they also have alarming rates of obesity (Poston et al., 2011; Durand et al., 2011;). Poston et al (2011) investigated the difference of overweight and obesity in firefighters compared to the general US population. Roughly 76% of career firefighters are overweight or obese compared to 68% of the general US population (Poston et al., 2011). In the present study, none of the firefighters were considered normal weight, which is deleterious to the overall health of firefighters. Researchers have indicated that augmented PA levels have been associated with decreased rates of obesity (Blair and Church, 2004). Therefore, wellness programs that incorporate increased PA levels could potentially mitigate the obesity levels in firefighters.

A strength of the current study was the ability to objectively measure physical activity while firefighters were on- and off-duty. The use of an objective measurement allowed researchers to examine how PA levels in firefighters differentiate between on- and off-duty days. The firefighters wore the accelerometer for the duration of the on-duty shift including medical and fire emergency calls.

A limitation of the study is firefighters' accelerometer data was only assessed during the hours when they were awake for on-duty and off-duty days. Firefighters wore the accelerometer for their whole 24-hour shift, but only wore it during hours the firefighter was awake when off-duty; therefore, the PA data could only be analyzed for waking hours. Finally, the participants were from the same department with the same tour format. Accordingly, these results may not be transferrable to a department with different tour structures.

As the results demonstrated, there is a dire need for increased PA levels in firefighters while on- and off-duty. The increased sedentary time can potentially increase firefighters' risk for a cardiac event when engaging in arduous emergency tasks. As a group, the firefighters in this study were not meeting the ACSM PA guidelines, which could be detrimental to the overall health and well-being of these firefighters. Firefighters must rely on their health to adequately perform the physiologically demanding tasks during an emergency. In the future, researchers must continue to collaborate with fire departments across the country to assess ways to enhance PA levels in firefighters.

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APPENDIX A. INFORMED CONSENT

NDSU North Dakota State University
Health, Nutrition, & Exercise Sciences
NDSU Dept 2620
PO Box 6050
Fargo, ND 58108-6050
701.231.7479

<u>Title of Research Study:</u> Relating Physical Activity and Injury to Fire Fighters' Ability to Perform High-Quality Cardiopulmonary Resuscitation.

<u>Who will conduct this study?</u>
Katie Lyman, PhD, ATC, NREMT, CKTF, Assistant Professor at NDSU
Allison Barry, MS, Doctoral candidate in Exercise Science & Nutrition at NDSU
Shelby Conard, ATC, Masters of Science: Advanced Athletic Training student at NDSU
Nathan Dicks, MS, Doctoral student in Exercise Science & Nutrition at NDSU
Kassiann Landin, MS, ATC, CKTP, Doctoral student in Exercise Science & Nutrition at NDSU

<u>Why am I being asked to take part in this study?</u>
We are looking to recruit 30 fire fighters to participate in this study. You are being asked to participate because the department physician has cleared you as an active member of the Fargo Fire Department.

Exclusions: You will be excluded from the study if: (1) you currently suffer from an injury or medical condition which precludes you from performing active on-duty tasks; (2) you have had a previous medical concern after engaging in vigorous exercise; or (3) you have an inability to perform treadmill walking with your issued bunker gear.

<u>What is the reason for doing the study?</u>
The research team would like to examine the physical activity levels as well as previous and current injuries and how they affect fire fighters' ability to perform high-quality CPR. As the number of medical calls increase, this allows not only researchers but also fire fighters to understand areas to improve in order to perform specific medical call tasks.

<u>What will I be asked to do?</u>
If you choose to participate, you will be asked to complete the following tasks:

1) **Physical Activity Measurement:** You will be asked to wear a physical activity monitor on your right hip via an elastic waistband for your nine-day tour. You will be asked to remove the monitor when you're sleeping at home (please leave it one when you're at the station) or when you're engaging in water activities.
2) **Questionnaires:** You will be asked to complete a physical activity questionnaire and injury questionnaires. The physical activity questionnaire to determine your physical activity level. The injury questionnaire will determine previous and current injuries.

Based on your initial responses to the injury questionnaire, you will be asked to complete additional questionnaires specific to the area you injured.

3) **CPR and exercise test:** The research team will fit you with a mouthpiece attached to a metabolic cart to analyze your cardiorespiratory fitness while performing CPR and the graded exercise test. You will be asked to perform five rounds of CPR on a QCPR Resuci Anne mannequin. Then you will perform a graded exercise test, walking on a treadmill at 3.3 mph with a 1% incline increase every minute. You will be asked to continue the graded exercise test until you are fatigued. Immediately after the exercise test, you will be asked to perform an additional five rounds of CPR.

Where will the study take place?

You will wear the accelerometer at home and at work during a typical 9-day tour. However, there is no maintenance of the accelerometer; therefore, this will take no time out of your day. You will be asked to come to the Bentson Bunker Field House (BBFH) on NDSU campus to complete the questionnaires, CPR, and graded exercise test. The CPR and graded exercise test will take place in the Human Performance Lab (lower level of BBFH). This will take roughly 1 hour.

What are the risks and discomforts?

The research team has reduced the known risks by taking precautionary measures. Although the researchers have taken the proper measures to reduce risks, it is not possible to identify all potential risks in research procedures.

1. Breach of confidentiality and/or privacy of data or health information (low risk).
    - Your information being disclosed or known to Fargo Fire Department (very low risk of occurring)

We will ensure the doors are shut and only the research team is present when you are filling out the questionnaires. We will keep your data in a locked cabinet in a locked office. When reporting the results to the Fargo Fire Department and the City of Fargo, the results will be presented as a group so there will be no way to individually identify each fire fighter. No participant will face employment issues based on his performance in this research protocol.

2. Exercise related discomforts (low risks)
    - Pain or discomfort while performing CPR and the exercise test
    - Lightheadedness or adverse cardiovascular responses

We will provide you with a warm-up prior to the start of the exercise test on the treadmill. You can quit at any time without repercussions if you feel like you can no longer engage in CPR and/or the graded exercise test. There will also be a certified athletic trainer present during the testing who is certified in CPR and use of AED.

What are the benefits to me?

You will be able to ask for your individual data for physical activity, quality of CPR, and the graded exercise test. You may not receive any additional benefits from participating in this study.

What are the benefits to other people?
We will be able to give information back to the Fargo Fire Department regarding the importance of physical activity, cardiorespiratory fitness, and the ability to perform high-quality CPR. This research will serve as a catalyst to improve physical activity levels and CPR.

Do I have to participate in the study?
Your participation in this study is completely voluntary. If you choose to participate in the study, you may withdraw at any time without repercussions. You will not have to explain your reason for quitting to the Fargo Fire Department and in no way will it affect your employment.

What are the alternatives to being in this study?
You do not have to participate in this study.

Who will see the information that I give?
Any records of the research that could be used to identify you will be kept private. Your information will be combined with other fire fighters who are participating in this study. When we give the results to the Fargo Fire Department and the City of Fargo, and we will write about the data that has been combined to include all participants. We may publish this data; however, your name and other identifying information will be kept private. Any information that you provide with identifying information will be separated from your data collected in the research study when stored under lock and key. This will allow your information to be deidentified. If you withdraw from the study at any point, your information will remain in the research record, but we will not collect any additional information from you.

Will I receive any compensation for taking part in this study?
After you complete the study, you will receive $50 from the City of Fargo in your regularly issued paycheck once the study is complete.

What happens if I am injured because of this research?
If you receive an injury in the course of taking part in the research, you should contact Dr. Katie Lyman at the following phone number 218-443-6446. Treatment for the injury will be available including first aid, emergency treatment and follow-up care as needed. Payment for this treatment must be provided by you and your third party payer (such as health insurance or Medicare). This does not mean that you are releasing or waiving any legal right you might have against the researcher or NDSU as a result of your participation in this research.

What if I have questions?
Before you decide if you would like to participate in this study, please be sure to ask any questions that come to mind right now. If you have any question while participating in the study you can contact Katie Lyman, katie.lyman@ndsu.edu, 218-443-6446 or Allison Barry, allison.barry@ndsu.edu, 701-306-6125.

What are my rights as a research participant?

You have rights as a participant in research. If you have questions about your rights, or complaints about this research you may talk to the researcher or contact the NDSU Human Research Protection Program by:

- Telephone: 701.231.8995 or toll-free 1.855.800.6717
- Email: ndsu.irb@ndsu.edu
- Mail: NDSU HRPP Office, NDSU Dept. 4000, PO Box 6050, Fargo, ND 58108-6050.

The role of the Human Research Protection Program is to see that your rights are protected in this research; more information about your rights can be found at: www.ndsu.edu/irb.

Your signature Date

____

Your printed name

____

Signature of researcher explaining study Date

____

Printed name of researcher explaining study

____

Documentation of release of images:
You also have the choice to allow all images obtained during this study to be used by the research team in outreach materials, publications, manuscripts, poster presentations, Powerpoint presentations, and University or other public websites. Images will only be used in a professional context when describing the study. Your name will never be associated with the images unless we obtain further permission from you at a later date. You have the choice of whether or not we can take your picture for professional outreach.

Yes _______

No _______

____ __________
Your signature Date

____
Your Printed name

APPENDIX B. SLEEP LOG

Subject ID:____________________________ Date start/end: ___________________

Actigraph #:____________

****Your information will be remain confidential (No personnel from FFD will have access to this data)****

Nine-day Tour	**Time you went to bed**	**Time you got up the next morning**
1st day		
2nd day		
3rd day		
4th day		
5th day		
6th day		
7th day		
8th day		

1. ***Off-duty days:*** only wear while you're awake
2. ***On*-duty days:** wear for full 24 hours including sleep
3. ***Do NOT wear when:***
    a. Showering/bathing
    b. Swimming or other pool activities
4. **Wear Actigraph on your *right hip*** as shown (see Fig. 1).

5. You will not need to charge the Actigraph.

6. Your exercise session is ________________________ at Human Performance Laboratory in the Bentson Bunker Field House at NDSU. Please bring your turnout gear to the exercise session.
7. When you arrive on campus please call/text Allie to get a parking pass and instruction on where to park.
8. If you can't attend the laboratory session please call Allie at 701-306-6125 or Katie at 218-443-6446.

APPENDIX C. DEMOGRAPHIC SURVEY

Fargo Firefighter Demographics Survey

1) Age: ________

2) Highest level of education completed:

    a. Less than high school
    b. High school
    c. Some college or associates degree
    d. Graduated college
    e. Master's degree or above
    f. Prefer not to answer

3) How many years have you been employed by the Fargo Fire Department? ____
    a. If any, how many years were you employed by a different fire department? ___________

4) What is your rank in the department? ___________________________

5) What classification(s) of fire fighter are you?
    a. Firefighter
    b. Captain
    c. Battalion Chief
    d. Assistant Chief
    e. Chief

6) How many times have you performed CPR on a patient? ___________ If never, please proceed to question 7.

    If you have performed CPR on a patient, how many incidents resulted in a positive patient outcome? _________

    If you have performed CPR on a patient, how many incidents resulted in a negative patient outcome (i.e, death or significant impairment? ________

7) Have you used high-fidelity equipment (e.g., a manikin that gives you feedback information) for CPR training?
    a. Yes
    b. No

8) Are you certified as a/an
    a. EMT
    b. Advanced EMT

c. Paramedic

9) What certifications do you have? (e.g., special fire certifications)
   a. Firefighter I
   b. Firefighter II
   c. Hazardous materials
      i. Hazmat operations
      ii. Hazmat technician
   d. Fire investigator
   e. Technical rescue
      i. Ropes I, II, III IV
      ii. Confined space I, II
      iii. Trench rescue I, II
      iv. Structural collapse