Do Counts From Wearable Fitness Devices Correlate With Performance-Based Tests of Work-Related Functional Capacity

By

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Abstract

The purposes of this study were to: (1) Determine the magnitude and direction of correlation between participant performance on five exercises taken from a Functional Capacity Evaluation (FCE) and scores from Actigraph activity monitors; and (2) Compare the results of two different placements of Actigraph devices. We used a cross-sectional design and convenience sampling to collect data from 46 healthy participants. Each participant completed five exercises while equipped with two Actigraph devices, one worn on the dominant side waist and one on the non-dominant wrist. The exercises included were 5-repetition maximum lifting (floor-to-waist, overhead and front carry), a sustained overhead work endurance task, and the 6-minute walk test. Analysis included calculating Pearson regression coefficients between maximum exercise performance and Actigraph vector magnitudes along with Intraclass Correlation Coefficients to compare the two Actigraph placements. Forty (86.9%) participants had complete data and were included in analysis. Participants were predominantly young (x=23.73), male (54.30%). Findings indicate Actigraph vector magnitude data from the device worn on the waist correlated positively ($r = 0.39$-0.64, $p < 0.001$ to 0.08) with maximum lift performance and the 6-minute walk test distance ($r = 0.66$, $p < 0.001$). Actigraph data from wrist placement was not significantly correlated with FCE items except when comparing average vector magnitude data and waist to crown lift ($r = 0.44$, $p < 0.001$). There was no significant correlation in either Actigraph placement for vector magnitudes and overhead work time. Intraclass correlation coefficients between the two Actigraph placements ranged from poor to acceptable agreement (ICC =0.24-0.70, $p < 0.001$ to 0.19). We conclude that Actigraph device output correlated moderately with maximum performance on FCE lift and ambulation tests. Waist placement appears more suitable than wrist

during performance-based tests. Actigraph devices may be useful during FCE evaluations and add another quantitative indicator of performance.

Preface

This thesis is an original work by Jesse Karpman. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name “Do Wearable Fitness Devices Correlate With Performance-Based Tests of Work-Related Functional Capacity?”, No. 00059490, DATE. 2015-11-03

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Chapter 1: Introduction

1.1 Problem Statement

Functional capacity evaluations (FCE) are performance-based tests typically conducted by physical, occupational and exercise therapists that measure an individual's ability to perform meaningful tasks on a safe and dependable basis. FCEs have two specific purposes. First, they measure an individual's potential to carry out job related tasks (i.e. lifting, carrying, climbing, etc.) and second, they identify if an individual has adequately recovered from an injury in order to return to workplace demands [1]. However, FCEs are lengthy, expensive, and only modestly predict future return to work [2,3]. It is also unknown how well FCE performance correlates with actual 'real-world' work ability. If a low correlation is observed between FCE results and workplace duties, one explanation might be low sincerity of effort [4]. However, there are other possible explanations that might impact correlation including psychological factors, workplace setting and expectations [5].

The use of accelerometers and wearable fitness devices in conjunction with FCEs may provide additional useful information about day-to-day function in workers. These devices are readily available and have the potential for evaluating activity within the context of work, allowing direct comparisons between levels of activity demonstrated during FCEs and levels required at work. Accelerometers are an easy, accurate way to measure level of activity and provide information about activity counts. Activity count information is used to derive information about activity intensity (i.e. light, moderate, vigorous) and can be displayed over varying epochs, or units of time. Despite the potential utility of accelerometers in evaluating physical function, it is unknown how accelerometry data correlates with FCE performance

The objectives of this study are to (1) quantify peak and average activity during selected FCE tasks, (2) to examine relationships between peak or average activity counts and peak performance during the FCE tasks and (3) to exam the relationship between activity counts from two placements of the Actigraph devices. If successful, this research will have two contributions. First it provides an opportunity to advance the application of wearable fitness devices into rehabilitation settings, and second, it adds another objective measure to the process of FCE. As these devices become more advanced and mainstream it is important for health care practitioners

to understand their clinical potential. Likewise, there are many benefits to improving the accuracy of FCEs while potentially decreasing assessment and evaluation cost in addition to assessment duration.

1.2 Literature Review

1.2.1 Background Research

Between 2005 and 2013, there have been a total of 2,539,651 total time loss injuries accepted by the Association of Workers' Compensation Board of Canada (AWCBC), with the highest yearly total in 2005 at 337,930 and the lowest in 2013 at 241,933. The yearly average over the nine-year span from 2005-2013 is 282,183 [6]. Between the years of 2011-2013 Alberta averaged 27,794 accepted injury claims per year. Between the years of 2005-2013, the 4 leading parts of body injured for accepted claims in order from most to fewest were lumbar region, shoulder, knee and lower back (unspecified). Lumbar region and lower back (unspecified) accounted for 16.3% of claims while shoulder accounted for 7.1% and knee for 6.4% [7]. The high proportion of claims related to lumbar and lower back pain are of specific importance as low back pain is one of the most difficult injuries to treat and diagnose, and is typically non-specific in nature with no identifiable findings on X-ray or MRI. This difficulty in assessing and evaluating low back pain increases the need for research on alternative tools or devices to provide another objective measure when working with patients with low back injuries.

1.2.2 Return to Work

A proper return to work (RTW) process should be used to help the worker re-integrate into the workplace. However, even with the abundance of research, the concept of RTW is poorly defined. Many studies define RTW as both a process and an outcome [8,9]. These definitions suggest that RTW is both complicated and complex with a variety of influencing factors. In Canada, the RTW process incorporates a variety of stakeholders each with their own specific outcome goals. Loisel et al. divides the stakeholders into 4 systems: the workplace system, legislative system, personal system and health care system [10]. The goals of these various groups at times conflict and as a result, meeting the goals of all involved in the process can be difficult.

1.2.3 Functional Capacity Evaluations (FCEs)

One way to determine whether a worker has reached a point in recovery in which it is suitable to return to work is through the administration of an FCE. FCEs have been defined as "*an objective measurement of a person's ability to perform functional work activities*" [11 pg. 2] Isernhagen explains the definition by breaking down the 3 components. Functional indicates purposeful activity and implies a definable movement that can be measured. Capacity indicates existing abilities including maximum function. Evaluation suggests a systematic approach that produces an outcome statement that is explanatory in nature [11 pg. 10]. Gross and Battié (2005) define FCEs as "*standardized batteries of functional measures commonly used to determine injured workers' abilities to perform work-related activities. Recommendations are made based on FCE results regarding employability, including whether a person can safely return to per injury or modified employment*" [12]. Isernhagen elaborates on FCE design by stating that 3 questions need to be answered to provide the information needed by all stakeholders. First, what can a person do safely? This first question deals with the injured worker's current ability level and matching appropriate work duties. As such, maximum levels of performance are measured. Ensuring that the work can be done without re-injury and further absenteeism is another key aspect of safety. The second question is what can the person do repetitiously? The ability to perform tasks repeatedly with proper mechanics and form is vital in being able to complete day-to-day work tasks. If fatigue is a factor and movements deteriorate after a short period of time then there is a higher likelihood of re-injury. Thirdly, did the person give full effort? This question has led to a large amount of research and debate. There is the potential for submaximal effort levels during evaluations to misrepresent abilities [11 pg. 10].

There are many different FCE models in practice. Each model has variations in characteristics such as the number of measurements obtained, underlying concepts and theories, and choice of measuring instruments [11, 13]. However, all models share the same common goal of attempting to objectively measure functional performance [13]. In Alberta, the Isernhagen Work System's protocol (since renamed the WorkWell protocol) is predominantly used [14]. The WorkWell systems protocol involves a 2-day test, the first of 3-4 hours and the second of 4-5 hours. This is done at a point where the workplace wants to determine if the worker is capable of returning to workplace duties. Patient history and musculoskeletal exams are required and done prior to

functional testing. Self-report instruments such as Pain Screening Questionnaire and Fear Avoidance Beliefs Questionnaire can be used in conjunction with the WorkWell protocol but are not mandatory. Aerobic testing is completed first using a 6-minute walk test followed by materials handling activities that include lifting, carrying and static push/pull. Non-material handling activities include common body movements expected during work tasks such as overhead work, forward bend, sitting, crouching and stair climbing and standardized hand-related testing requiring grip strength and hand coordination [11 pg. 510-511].

Previous studies have been done comparing the results from FCE items and the likelihood of RTW. Matheson et al. compared pounds of load for various items and RTW. Workers who did RTW had floor to waist lifts averaging 37.7 lbs, waist to overhead lift averaging 27.9 lbs, and horizontal lifts averaging 45.0 lbs. These are compared to weights of 22.9, 21.1 and 32.9 respectively for workers who did not RTW. Grip force, however, did not show significant differences between the groups. They concluded that greater lifting ability resulted in greater likelihood of RTW [15]. In another study comparing time on total temporary disability benefits and FCE performance, Gross et al. found that better performance on FCEs was related to faster benefit suspension and claim closure, while concluding that overall performance was weakly associated with faster recovery [14].

Another important consideration with FCEs is the term function. With the introduction of the International Classification of Functioning, Disability and Health (ICF) in 2001, health conditions are now viewed as an interaction between bodily functions and structures, activities, participation, environmental and personal factors [44]. In the context of our study, FCEs mainly focus on the ‘activity’ and ‘participation’ aspects of function, as these are the concepts related to work. FCE items are tests of activity, but recommendations are being made about actual participation in real-world work. Function also varies from individual to individual, as it is dependent on their activities or participation; thus a specific impairment may be a limiting factor in participation or activity for one individual, but not for another in a different context.

1.2.4 ActiGraph Accelerometers

Recently, more and more physical activity research has involved the use of accelerometer-based activity monitors. These monitors have the potential to provide more detailed and comprehensive information about movement in both clinical and lifestyle research. In terms of FCE, this is important as wearable activity monitors may enhance the validity of functional testing, including allowing measurement of movement while the patient conducts actual work activity at the workplace. Currently FCEs are largely dependent on judgments of safe maximum levels from either patients (psychophysical testing) or therapists (kinesiophysical testing), with the debatable reliability and validity that accompanies these judgments. Improved measurement of movement, which can be related to potential for function, will improve workability determinations and communication between stakeholders involved in making return-to-work decisions. Furthermore these monitors are commercially available and affordably priced [16].

Accelerometers have the ability to measure uniaxial or triaxial movements and are usually worn on the waist or wrist. The ActiGraph is a piezoelectric sensor that generates signal based on movement [17]. The newest model, the wG3TX-BT, is a triaxial accelerometer that is commonly used in research and costs $225 USD. The wG3TX-BT is marketed as a research instrument and is one of the most commonly used for free-living physical activity assessment [18]. Motion data is collected from vertical (Y), horizontal right-left (X) and horizontal front-back (Z) axes and "raw" mode output allows the researcher to select various sampling rates ranging from 30 to 100 Hz [19]. The wG3TX-BT is able to accurately record accelerations ranging in magnitude between 0.05 – 2.5 Gravitational units on all three axes. Activity counts are then calculated using the absolute change in acceleration over cycle period times or epochs. Vector magnitudes (VM) can be calculated using the vector-summed value $\sqrt{X^2Y^2Z^2}$. These can be used to show a larger picture of motion and can be beneficial in more complex motion as compared with simple movements in a single plane.

Various studies have found this accelerometer to be valid for estimating energy expenditure, and tracking movements and exercise repetitions [17,20,21,22]. Santos-Lozano et al. analyzed the inter-monitor reliability of the ActiGraph device and found an overall good inter-instrument reliability across all planes [20]. This study suggests that there is minimal difference between

devices and as such, results are unlikely to vary between G3TX devices. Since many studies use more then one device placed at varying locations on the body (commonly waist, wrist and ankle), it is important to be able to eliminate inter-device error. Stec and Rawson found net energy expenditure during resistance training, assessed using a Cosmed K4b2 portable indirect calorimeter, was significantly correlated to counts from all the axes and VM for G3TX devices worn on the waist but did not significantly correlate with VM counts on the wrist or ankle. They further discussed how resistance training involves some limbs being active while others are inactive making the location of accelerometer placement key for validity of the data collected [21]. Chen et al. had similar findings when using a hip and wrist placement for measuring energy expenditure. They found that a combination model was most accurate for energy expenditure prediction, with the waist monitor data for weight bearing activities and the wrist monitor during more sedentary activities with lower intensities [23]. However, there are few studies that use accelerometer data to classify specific movements or activities of individuals. One such study by Karantonis et al. studied the ability to classify movements based on real time accelerometer data. Movement classes involved postural orientation, walking and falls. The overall accuracy of prediction ranged from 63.3% for walking at a slow speed to 100% accuracy for stand-to-sit, lying-to-sit, sit-to-lying, and falling events both active and inactive [24]. Another such study by Bonomi et al. used a decision tree model to attempt to identify types of physical activity, the duration of activities, and their intensity. This model was found to be 100% accurate in classifying lying and running but only 59% accurate in classifying standing [25]. While these studies were able to classify movement reasonably well, there are no current studies comparing activity counts with time of activities or weight of resistance during activity. Also, despite the potential utility of accelerometers in evaluating physical function, it is unknown how accelerometry data correlates with performance during FCE.

1.3 Specific Goals

The objectives of this research were:

1) To describe activity counts during 5 FCE items selected from the WorkWell FCE protocol (waist-level lifting, overhead lifting, front carry, elevated work, and 6-minute walk test) using ActiGraph devices on healthy adult individuals.

2) To determine the correlation between ActiGraph magnitude values and weight lifted during the waist-level and overhead lifting tasks.
3) To determine the correlation between ActiGraph magnitude values and time or distance of exercise during the overhead work test and 6-minute walk test.

Secondary objective:

1) To compare activity counts and correlations between Actigraph values on devices placed on the dominant side of the waist and the non-dominant wrist.

1.4 Hypotheses

The overall objective of this research was to gather preliminary information and data and as such this research was exploratory in nature. Since no similar research has been done, it was unknown to what magnitude the measures might correlate or whether the correlations would be positive or negative during the lifts and overhead exercise. Therefore, our null hypothesis was that there is no statistically significant correlation between activity monitor outputs and maximum performance on the lifting and carrying FCE items or the sustained elevated work task.

It was hypothesized for the 6-minute walk test that there would be a positive correlation of fair to moderate magnitude ($r=0.25$-0.5) (34) between total activity counts and distance of walking.

Reasoning: It was hypothesized that individuals with higher activity counts, by definition, would move the ActiGraph devices more. As such it was expected that with higher rates of movement of both the hip and the wrist that a farther distance will be walked.

Related to the secondary objective, it was hypothesized for the floor to waist, waist overhead, horizontal carry and 6MWT that a good ICC agreement of 0.6-0.74 (35) would be found between the Actigraphs on the wrist and the waist and that a poor agreement of ICC ≤ 0.4 would be found on the weighted overhead work.

Reasoning: It was expected that the vector magnitudes found from the Actigraph on the wrist would be higher as more movement is generally expected in the arms then the waist. However, the slopes, and therefore correlations should not be different and therefore a good agreement should be found between Actigraph placements.

Chapter 2: Methods

2.1 Study Design

A validation, cross sectional design was used to evaluate the ActiGraph devices worn by participants during FCE activities. A cross sectional design allowed for data to be collected efficiently and at a specific point in time. This study design provided some advantages. Cross sectional studies allow for quick and routine data to be collected. Due to the analysis being correlational, this type of study provides data that is easily comparable at a given time. Since the data from the ActiGraph is being compared with results from the FCE and FCEs are considered the gold standard in return to work, the validation is concurrent in nature. The data collection was primary in nature, which provided the benefit of allowing for changes or modifications in what data was collected. This study was approved by the University of Alberta's Health Research Ethics Board.

2.2 Sampling

Convenience sampling was used to enroll participants. Specifically, participants were recruited via word of mouth and social media. A recruitment poster was posted on the researcher's personal social media pages with information on how to contact if interested in participating (Appendix 4). Subjects, either male or female, needed to be healthy individuals between the ages of 18-65 years. Subjects were excluded if they were injured or had any physical limitations that would hinder their ability to complete certain exercise components from the FCE. This was determined using the Physical Activity Readiness Questionnaire (PAR-Q - revised 2002) (41). Once a volunteer had expressed interest in taking part in this study, they were asked to complete the PAR-Q to ensure they met inclusion criteria (Appendix 5). If the participant answered yes to any questions on the PAR-Q it was determined on a case-by-case scenario through discussion with Dr. Gross if that individual was still suitable to participate. In 2 instances an individual answered yes to the question: *do you lose your balance because of dizziness or do you ever lose consciousness* and in 2 other instances individual answered yes to the question: *do you have a bone or joint problem that could be made worse by change in your physical activity* and in one instance an individual answered yes to the question: *in the past month have you had chest pain*

when not doing physical activity (PAR-Q 2002 questions 3/4/5), however in all situations they had previously consulted a doctor regarding the condition and were not currently limited by these factors. As such they were deemed eligible to participate. If there was no reason to exclude the individual, then a time suitable for both the participant and researcher was arranged to conduct testing.

A sample size of 40 was required based on an alpha level of 0.05 and a power of 80%. This value was calculated using Power and Statistical Software (PASS) based on the following parameters: $\rho 1 = 0.00$ and $\rho 2 = 0.4$ (midpoint of predicted fair to moderate correlation). We added an additional 6 participants to account for attrition (i.e. participants stopping testing) or errors during data collection, making a total sample size required of 46. Due to the broad inclusion criteria for participants and few exclusion criteria, it was not difficult to meet the sample size needed.

2.3 Data Collection

After informed consent was obtained, all participants were equipped with 2 ActiGraph wGT3X-BT devices that had been initialized using the ActiGraph 6 software. The Actigraph device has been found to be reliable and valid for various forms of lifestyle and physical activity related research [17,20,21,22]. One device was worn on the non-dominant wrist and a second device was worn on the waist located on the anterior superior iliac spine on the dominant side using a belt style strap. Previous studies have compared Actigraph output based on device placement, with a significantly higher raw output seen from devices worn on the wrist in comparison to those worn on the hip [26]. Other studies have shown that device placement on the waist provided more accurate estimates of energy expenditure over wrist placement [23,27]. However the wrist placement may be more comfortable and practical. Participants were also asked to wear a Polar heart rate monitor, which was part of the FCE protocol for determining maximum heart rate levels.

Figure 1: Placement of Actigraph devices and Polar Heart Rate Watch

After devices were attached, each participant underwent 5 exercises taken from the 'basic' WorkWell FCE (described in more detail in the Section 2.4). Three lifting exercises were completed in sets of 5 repetitions maximum. The fourth exercise was sustained, weighted elevated work, an exercise that is commonly performed in FCE protocols for patients with upper extremity injuries. The last exercise was a 6-minute walk test (6MWT). After all 5 exercises had

been completed the ActiGraph data was downloaded using the Actilife 6 software and exported to a Microsoft excel file.

Each exercise was completed after an explanation and demonstration had been given and any questions had been answered. The evaluator (JK) was trained in how to conduct these FCE items by a trained and experienced occupational therapist that is a practicing WorkWell FCE evaluator. A practice session was also held with the research team before formal testing began. All testing was conducted in the Functional Performance lab in Corbett Hall at the University of Alberta. The time to complete each task was logged using the computers clock, which the devices were previously synced (to the nearest 5 millisecond interval) at the beginning and end of each set of 5 repetitions along with the corresponding weight lifted. The Bluetooth feature on the Actigraph devices allowed for data to be seen in real time on the Actilife software. Progressive isoinertial testing was completed. After each set of lifts, if the participant believed they could safely increase the weight, and there were no signs of observable stopping criteria (42,43), as noted in section 2.4, then more weight was added and the participant once again completed a 5-repetition set. A rest period of maximum two minutes was provided between sets, or once heart rate had dropped to around 100 beats per minute. This time was used to change the weights and isolate activity counts between sets.

2.4 Measures

Actigraph - The ActiGraph is a piezoelectric sensor that generates signal based on movement [17]. The wG3TX-BT is a 3-axis accelerometer. Previous studies have shown the Actigraph to have high inter-monitor reliability [20] and moderate validity for estimating energy expenditure, tracking movements and exercise repetitions [17,20,21,22]. The Actigraph displays data for each individual axis or as the square root of the squared sum of each axis (known as the vector magnitude). The Actigraph collects raw data, which was displayed at varying epoch times. These epoch times are selected at the time of importing the raw data into the Actilife software. Due to the short nature of the selected FCE exercises, 5-second epochs were chosen. Each set of weighted lifting exercise took a maximum of 90 seconds. With 5-second epochs a maximum of 18 VM were recorded. The first 5-second epoch used for analysis were once the exercise began

with the final 5-second epoch being upon completion of the exercise. Ultimately, the measure used was vector magnitudes over a 5-second epoch at 60hz for this study.

Functional Capacity Evaluation - The 5 FCE items were selected from the broader WorkWell FCE protocol. Three different manual handling tasks (floor-to-waist and overhead lift along with front carry) were completed. Two systematic reviews have been conducted on the WorkWell FCE protocol. Kuijer et al. found that 13/14 studies suggested the lifting items are predictive of RTW [28]. Bieniek and Bethge found the manual handling exercises to have high inter-rater reliability, intra-rater reliability and test-retest reliability [29]. Weighted elevated work was also conducted, which within the protocol assesses posture, mobility and upper extremity endurance. Brouwer et al. found the overhead work test to have a high kappa agreement percentage, but a low ICC in test-retest reliability [30]. The 6-Minute Walk Test (6MWT) was also conducted to assess walking capacity. The 6MWT is a common test across a variety of FCE protocols. This test has shown to be a valid instrument in testing exercise capacity across all ages [31,32]. In more description, the FCE items are as follows:

5-repetition max floor to waist level lift - A crate with weights (<5kg) begins on a shelf at waist height, where a participant with hands on the crate would have elbows flexed to 90 degrees. The participant then lifts the crate from the shelf, turns 90 degrees, squats to place the crate on the floor, and then lifts it back up to the shelf. The tester watches for proper body mechanics such as using legs to lift instead of the back and holding the crate close to the body. If at any time the participant reports discomfort or begins to counterbalance, use momentum, lose control of the weights or show fatigue, then the test is stopped as the maximum safe lift weight has been reached. For this lift, the maximum weight lifted (in kilograms) was used for analyses and compared to average vector magnitude and peak vector magnitude from the ActiGraph device during the maximum performance. This analysis is outlined in Table 1.

Figure 2: Starting position for all three lifting exercises. Shelf is placed at about waist height and elbows at about 90 degrees when hands are grasping the handles.

5-repetition max waist to crown level lift - A crate with weights begins on a shelf at waist height. The participant lifts the crate from the shelf, places it on a higher shelf at eye level, and then brings the crate back down to the waist-height shelf. The tester watches for proper body mechanics such as using legs to lift and keeping the back straight. If at any time the participant reported discomfort or began to counterbalance, use momentum, lose control of the weights, show excessive recruitment of trapezius muscle, or show fatigue then the test was stopped as maximum safe lift weight has been reached. For this lift, the maximum weight lifted (in kilograms) was used for analyses and compared to average vector magnitude and peak vector magnitude from the ActiGraph device during the maximum performance.

Figure 3: Position of top shelf for waist for crown level lift. Shoulders at about 90 degrees and top of the box in line with crown of your head

Front (horizontal) carry - A crate with weights begins on a shelf at waist height. The participant lifts the crate from the shelf, walks a distance of 25m keeping the crate at about the same height level, and then returns to the starting point to place the crate back down. The tester watches for proper body mechanics such as using legs to lift, keeping back straight, equal weight bearing and consistent step length. If at any time the participant reported discomfort or began to counterbalance, show asymmetrical loading, lose control of the weights, take smaller steps, take uneven steps or show fatigue, then the test was stopped as maximum safe lift weight has been reached. For this lift, the maximum weight lifted (in kilograms) was used for analyses and compared to average vector magnitude and peak vector magnitude from the ActiGraph device during the maximum performance.

Weighted overhead work until fatigue - A perforated board at about crown level had bolts and nuts facing outward. A 3-pound Velcro weight was worn on each wrist. The participant works at crown level, being kept busy by screwing and unscrewing the nuts and moving them from one bolt to another. There was no set pattern in which the participant followed, as long as both hands remained elevated at a height in line with the bolts. Time started as soon as the participant raised their arms to begin work. The tester watched for thoracic extension, attempts to rest arms, shoulder hiking or elbow dropping. If any of those actions were noticed or if the participant dropped one or both arms, the test was stopped. For this exercise, total time of exercise was used for analyses and compared to the average vector magnitude from the ActiGraph device.

Figure 4: Work position for the overhead work task

6-minute walk test - A long, flat corridor with a hard surface was marked with tape as turn around points (it was not recommended to use a treadmill). In this study, each turn around (lap) represented 25 meters. The tester had a timer and lap counter to keep count of the distance travelled. The tester ensured that a steady pace was maintained, there were no gait deviations, or changes in weight bearing. If any of those actions were noticed, or if the participant reported discomfort, then testing was stopped. For this exercise, distance (in meters) was used for analysis and compared to total activity count from the Actigraph.

Potential Confounders – One of the potential confounding variables of concern during this study was the effect of feedback or comments from the FCE examiner. To limit this, there was no feedback given to participants during the exercises and all exercises were explained using a standard script (Appendix 7). As many participants were recruited via word of mouth, it was also asked by the researcher that the exercises not be explained to other potential participants in detail to prevent any form of preparation that could have impacted the results.

2.5 Data Analysis

Descriptive statistics were calculated including mean and range for both demographic data and measures. Exercises that were weight based were analyzed using descriptive statistics in the form of mean, standard deviation, and range. Exercises that were time based were also analyzed using descriptive statistics in the form of mean, standard deviation, and range.

Next, two sets of inferential statistics were calculated. First, the association between FCE variables (time or weight lifted) and Actigraph variables (peak or average vector magnitudes) from the Actigraph placed on the dominant side waist were analyzed using Pearson Correlation with 95% confidence intervals. Second, the association between FCE variables (time or weight lifted) and Actigraph variables (peak or average vector magnitudes) placed on the non-dominant wrist was analyzed using Pearson Correlation with 95% confidence intervals. Magnitude of the Pearson correlation values was evaluated using criteria from Portney & Walkins, with 0-0.25 indicating none to poor, 0.25-0.5 indicating fair to moderate, and 0.5-0.75 indicating moderate to good, and above 0.75 indicating excellent correlations (34).

Intraclass Correlation Coefficients (ICC) were used to determine if the two Actigraph placements provided consistent measures using two-way random effect models, consistency agreement and average measures. A two-way random effect model was used as both the sample and the Actigraph devices are from random samples. As it was expected that data from the wrist would be higher than the waist, consistency agreement was used to analyze linear trend. Average measure considers the average from both devices being used through out all the data. ICC values were evaluated using criteria from McDowell (35), in which ICC above 0.75 indicate excellent inter-rater agreement, 0.6 to 0.74 shows good agreement; 0.4 to 0.59 indicates fair to moderate, and below 0.4 is poor agreement.

Table 1: Table of outcomes for correlation analyses

Exercise	Variable 1	Variable 2
i. Lifting (FTW,WTC,FC)	Maximum Weight (kg)	Average vector magnitude
ii. Lifting (FTW,WTC,FC)	Maximum Weight (kg)	Peak vector magnitude
iii. Overhead work	Time (seconds)	Average vector magnitude
iv. 6MWT	Distance (meters)	Total activity counts

Statistical analysis was performed using SPSS on a computer in Corbett Hall at the University of Alberta. All data used an alpha value of α=0.05.

Chapter 3: Results

3.1 Participant Characteristics

In total 46 participants were recruited for this study. 54.3% of the subjects were male and 89.1% were right handed. The mean age of the sample was 23.7 years, and the mean height and weight were found to be 170 cm and 73.2 kg respectively. There was no difference in age between males and females? ($p=0.128$), though males were older by a mean of 1.7 years. Males were found to have a significantly higher mean height ($p<0.001$) by 16 cm and a significantly higher mean weight ($p<0.001$) by 20.6 kg. Full demographics are found in table 2.

Table 2. Participant demographics

	Total	Male	Female	Total	Male	Female
	Mean (SD)			Min-Max values		
Age	23.7 (3.7)	24.5 (4.1)	22.8 (3.0)	19-40	19-40	19-34
Height (cm)	170 (10.8)	177 (8.5)	161.6 (6.1)	152-194	157-194	152-172
Weight (kg)	73.2 (18.0)	82.6 (17.0)	62.0 (11.7)	43-135	46-135	43-90
Male	54.3%					
Right-Handed	89.1%					

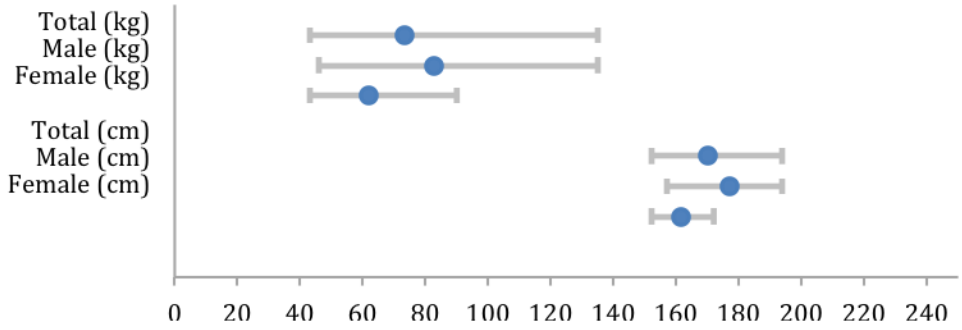

Figure 5: Ranges in Height and Weight of participants in FCE exercises

3.2 Functional Capacity Evaluation Performance Characteristics

Five exercises were chosen from the Basic WorkWell FCE protocol for this study. Thirty nine of the 46 participants (84.78%) had no missing data (see Figure 6). Each participant completed three lifting exercises. The front carry was found to have the highest mean maximum weight lifted (36.9 kg) followed by the floor to waist level lift (30.7 kg) and the waist to crown level lift (20.9 kg). Both sexes followed the same trend as above for sex-specific average maximum weight lifted. The front carry was also found to have the largest range with 52.2 kg, followed by floor to waist with 44.2 kg and lastly waist to crown level with 35.2 kg. Again, both sexes followed the same trend as above for sex-specific ranges (See Table 3).

The sustained, weighted overhead work exercise took on average 2 minutes and 31 seconds. Males were found to have a notably larger range than females. The 6-minute walk test was the last exercise completed. The mean distance walked was 457.2m, with only a slight difference in means between males (459.8m) and females (454.0m). Full descriptive Statistics for FCE item performance is shown in Table 3.

Table 3. **Descriptive statistics for FCE item performance.**

	Total	Male	Female	Total	Male	Female
	Mean (SD)			Min – Max Values		
F-T-W weight (kg)	30.7 (11.8)	38.8 (9.0)	21.0 (6.1)	14.0-58.2	23.0-58.2	14.0-37.8
W-T-C weight (kg)	20.9 (8.0)	26.5 (6.3)	14.3 (3.3)	9.4-44.6	16.2-44.6	9.4-21.9
FC weight (kg)	36.9 (13.4)	45.7 (10.1)	26.4 (8.1)	15.1-67.3	24.2-67.3	15.1-43.5
OW time (minutes)	2:31 (1:27)	3:00 (1:43)	1:56 (0:44)	0:58-8:18	1:05-8:18	0:58-3:38
6MWT distance (meters)	457.1 (55.2)	459.8 (41.9)	454.0 (68.9)	350-625	381.25-560	350-625

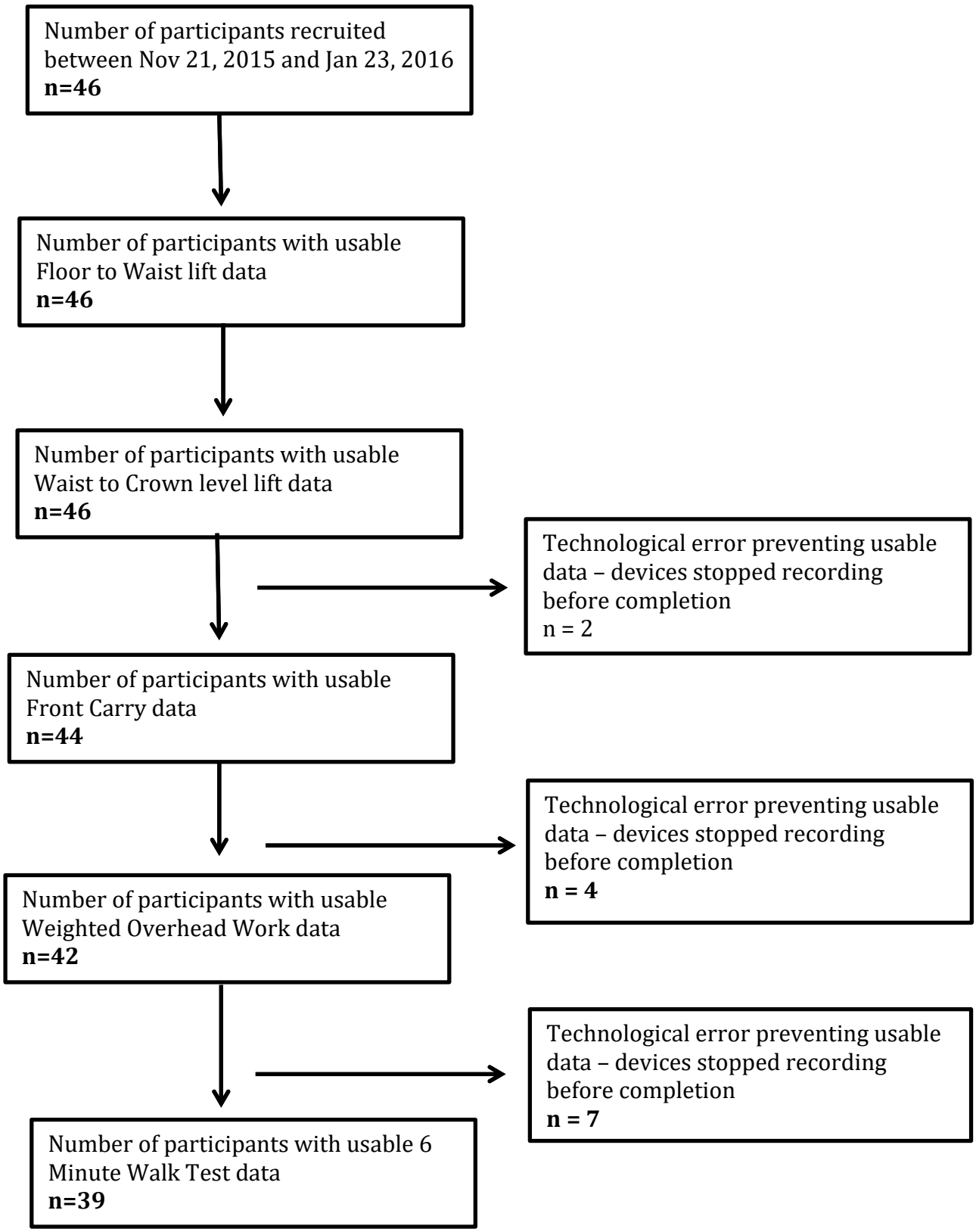

Figure 6. Flow chart showing usable participant data sets from the various FCE exercises

3.3 Pearson Correlations Between Functional Capacity Evaluation Performance and Actigraph Data

The correlational analysis was completed amongst the vector magnitudes from the devices placed on the dominant side waist and the non-dominant wrist. In total 12 Pearson correlations were calculated using a 2-tailed test and a significance of $p<0.05$. The maximum weight lifted during the floor to waist lift was found to have a statistically significant positive correlation at a magnitude judged to be fair to moderate for both peak ($r=0.40$) and average (0.45) vector magnitudes. Both peak and average vector magnitudes correlations from the waist placement were significant. In contrast, a non-significant correlation with both peak and average vector magnitudes was observed from the wrist placement ($r=0.18$, $r=0.18$). The maximum weight lifted during the waist to crown level correlated significantly and positively at a magnitude judged to be fair to moderate with both peak ($r=0.39$) and average ($r=0.39$) vector magnitudes from the waist. The average vector magnitude from with wrist was also significant ($r=0.44$). A non-significant correlation was found from the peak vector magnitude at the wrist ($r=0.15$). The maximum weight lifted during front carry was found to correlate significantly and positively at a magnitude judged to be moderate to good, with both peak ($r=0.57$) and average ($r=0.64$) vector magnitudes from the waist placement being significant. Non-significant correlations were observed for peak ($r=-0.13$) and average ($r=0.24$) vector magnitudes from the wrist. Correlation results for the FCE lift items are presented in Table 4.

Table 4. Correlations between maximum weight lifted and vector magnitudes from waist and wrist Actigraph placements.

		Peak Waist VM	Average Waist VM	Peak Wrist VM	Average Wrist VM
Floor to Waist Max Weight	Pearson Correlation	**.40**	**.45**	.18	.18
	Sig. (2-tailed)	.005	.002	.230	.245
	N	46	46	46	46
Waist to Crown Max Weight	Pearson Correlation	**.39**	**.39**	.15	**.44**
	Sig. (2-tailed)	.008	.007	.314	.002
	N	46	46	46	46
Front Carry Max Weight	Pearson Correlation	**.57**	**.64**	-.13	.24
	Sig. (2-tailed)	<0.001	<0.001	.402	.117
	N	44	44	44	44

Values in bold significant at p=0.01

Correlations were also calculated between weighted overhead work time with average vector magnitude from both the dominant side waist and non-dominant side wrist placement. Peak was not calculated as this exercise was endurance and not maximal ability based. A non-significant correlation was found between total time in minutes and both average vector magnitude from the waist and wrist placement. These results are presented in table 5.

Table 5. Correlations between Weighted Overhead Work time and average vector magnitudes from waist and wrist Actigraph placements.

		Average Waist VM	Average Wrist VM
Total Time	Pearson Correlation	-.07	-.21
	Sig. (2-tailed)	.665	.188
	N	42	42

Distance covered during the six-minute walk test was correlated with total activity count (sum of vector magnitudes over the full 6-minute period) from both Actigraph placements. Total distance was found to have a statistically significant, positive correlation at a magnitude judged to be moderate to good correlation (r=0.66) with total activity counts from the waist placement. A non-significant correlation was observed between total distance walked and total counts from the wrist placement. Results are presented in table 6.

Table 6. Correlations between Six-Minute Walk Test distance and total activity counts from waist and wrist Actigraph placements.

		Total activity counts - waist	Total activity counts - wrist
Total Distance	Pearson Correlation	**.66**	.23
	Sig. (2-tailed)	<0.0001	.163
	N	39	39

3.4 Intraclass Correlation Between Actigraph Device Placements

Actigraph Devices were placed on the dominant side waist on the Anterior Superior Iliac Spine and non-dominant wrist for the duration of the study. Data were compared from both placements using ICC for all 5 exercises. ICCs are calculated for two-way random effect models, consistency agreement and average measures. For floor to waist lift and front carry exercises the peak vector magnitude between the two placements were found to have poor agreement (ICC=0.36, ICC=0.24 respectively). For waist to crown lift peak vector magnitudes between the two placements were found to have fair agreement (ICC=0.45). Average vector magnitudes for the Actigraph placements of the floor to waist lift and waist to crown lift were found to have fair agreement (ICC=0.53, ICC=0.59) respectively, while good agreement was found for the front carry lifts (ICC=0.70). Results are presented in table 7.

Table 7. Intraclass Correlation Coefficients between two placements of Actigraph during three lifting exercises.

	Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound
Floor to waist using peak VM	.36	-.17	.64
Waist to crown using peak VM	.45	.01	.70
Front carry using peak VM	.24	-.39	.59
Floor to waist using average VM	.53	.15	.74
Waist to crown using average VM	.59	.26	.77
Front carry using average VM	.70	.46	.84

ICCs were also calculated for device placement for the weighted overhead work exercise and six-minute walk test. For the overheard work exercise only average vector magnitudes were used. Placement of the two Actigraph devices was found to have poor agreement (ICC≤0.4) for overhead work. For the six-minute walk test total activity counts were used in the analysis. Placement of the two devices was found to also have poor agreement (ICC≤0.4) for the 6-minute walk test. Results are presented in table 8.

Table 8. Intraclass Correlation Coefficient between two placements of Actigraph during weighted overheard work and 6-minute walk test exercises.

	Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound
Weighted overhead work using average VM	.30	-.30	.62
6-minute walk test using total activity counts	.27	-.39	.62

Chapter 4: Discussion

4.1 Key Findings

Four key findings emerged from this study. First, there is a positive, moderate correlation between Actigraph device vector magnitudes and maximum weight lifted when the Actigraph device was placed on the participant's waist. Second, there was a very small correlation between Actigraph device vector magnitudes and performance on the sustained, weighted overhead work test. Thirdly, there was a positive, large correlation between total activity counts from the Actigraph device and total distance walked during the six-minute walk test when the Actigraph was worn on the participant's waist. Finally there was a poor agreement between Actigraph device vector magnitude scores from the two placements of the Actigraph device on the dominant side waist and non-dominant side wrist. Although our study was exploratory in nature, our study may have implications for use of these Actigraph devices in occupational rehabilitation and assessment of work ability.

We made three hypotheses prior to conducting our study. The first was that there would be a statistically significant correlation between Actigraph monitor outputs and maximum performance on the lifting and carrying FCE items and the sustained elevated work. This hypothesis was only supported for the lifting and carrying activities when the Actigraph device was worn on the participant's waist. Our second hypothesis was that a positive correlation of moderate magnitude would be found between total activity counts and walk distance during the six-minute walk test. This was again only supported when the Actigraph device was worn on the participant's waist. Our third hypothesis that we would find a good agreement when comparing Actigraph outputs from the waist and wrist placements. Surprisingly, this hypothesis was not supported. This indicates that the waist is likely the optimal placement of the Actigraph device for measuring level of activity during FCE testing. Placement on the wrist likely generated too much 'noise' for accurate measurement of activity levels, and the Actigraph does not appear to be a good measure of sustained postural activities.

To our knowledge this is the first study to compare data from a wearable fitness device and maximal performance on specific FCE items. Our study appears to be the first to examine using a wearable fitness device for short burst, maximal performance exercises as opposed to lifestyle activities. In the past, wearable devices have been used to determine cut points or activity levels on a day-to-day basis (17,22,27) or to compare energy expenditure results,

(18,21,23,26) but we have not found studies that specifically compared device output and maximal performance. The study conducted by Stec and Rawson, although looking to predict energy expenditure, was the only study in which Actigraph devices were placed on various positions on the body while conducting weight based exercises (21). Our research was similar to that of Stec and Rawson in that both found the wrist placement of the Actigraph provided greater VM counts than the waist placement (21). That data was then used in different analysis. Stec and Rawson found that net energy expenditure was significantly correlated with the VM counts at the waist but not the wrist, while we found that weight lifted was significantly correlated with VM counts at waist but not always at the wrist. Can you make a statement summarizing? Both studies seem to favour the waist worn monitor?

4.1.1 Relationship between Actigraph VMs and FCE lifting exercises

Actigraph vector magnitudes from waist placement of the Actigraph device were found to correlate with maximal performance on three lifting exercises from the WorkWell Protocol. We found there to be a statistically significant, positive correlation that was fair to moderately sized between maximal performance and both peak and average vector magnitudes from the waist placement of Actigraph for floor to waist and waist to crown lifts. We also found there to a statistically significant, positive correlation that was moderate to large between maximum performance and both peak and average vector magnitudes from the waist placement of Actigraph for the front carry lift. The only statistically significant correlation with the wrist placement was a positive correlation that was fair to moderately sized between average vector magnitude and waist to crown lift. Finding significant correlations from the lifting exercises is important, as performance on FCE lifting tests have been found to be the most predictive of RTW (14,15).

We expected to find significant correlations, however we were unsure which direction or between what vector magnitude variable. Across all three exercises a stronger correlation was found between average waist vector magnitudes and maximum weight than for peak vector magnitudes. This is likely due to the fact that when using average vector magnitudes, you attenuate the chance of outlier data points or random ‘noise’ impacting results. Like with any set of exercises, it is possible that an individual pushes harder on the last repetition in that set, or

alternatively, fatigues as the set progresses. This change in movement or pace would also influence the correlation with peak vector magnitudes more than average vector magnitudes.

It is also interesting to note that the waist to crown lift had the weakest correlation of the three lifts at r=0.39 for peak and r=0.39 for average, while the front carry had the strongest at r=0.57 for peak and r=0.64 for average. This can be explained by considering the mechanics of the exercises. The waist placement of the Actigraph is much closer to the body's center or mass. The waist to crown lift would have involved the least amount of movement of the center of mass of the body, as this exercise focuses more on upper extremity strength and has minimal displacement of the centre of mass. We would expect the limiting factor in this exercise to be shoulder and arm strength, which the waist placement may not be overly sensitive to. This could also be the reason why the only significant correlation found with data from the wrist placement of the Actigraph device was during this exercise. In comparison, the front carry involves the most movement of the center of mass and this resulted in the strongest correlation. The limiting factor in this exercise would be both leg and trunk strength, which the waist placement would be more sensitive for detecting.

When correlating data from the wrist placement of the Actigraph and maximum weight lifted, only one significant correlation was found. This was the correlation between average vector magnitude and maximum weight lifted during the waist to crown level lift. In this case, unlike the waist placement with all three of the lifting exercises, there was only a correlation found with average vector magnitudes but not with peak. More discussion on why fewer correlations were seen with the wrist placement will be provided at a later point, when considering the ICC values.

4.1.2 Relationship between Actigraph VMs and FCE weighted overhead work

When determining what exercises to use from the WorkWell FCE protocol, we wanted to include one exercise that measured fatigue or endurance for an activity. We decided on sustained, weighted overhead work since it involved use of the upper extremity. This exercise was modified slightly from the protocol in that for the original protocol after 2 minutes the exercise is marked as complete. For this study we removed the time limit and participants worked until fatigue/failure. A very large range in times was found for this task with the shortest time being 58 seconds and a maximum time of 8 minutes 18 seconds. However, the median time

found was toward the shorter duration at 2:08. As previously mentioned, due to the nature of this exercise being endurance and not maximal strength, we decided to consider only average vector magnitudes and not peak. It was found that Actigraph vector magnitudes from neither the waist nor wrist placements were significantly correlated with total time of weighted overhead work task.

Out of all the exercises conducted during the study, sustained overhead work was the one in which there was the most uncertainty in our hypothesis. There was no previous literature found on endurance tasks and activity monitor output. As well, out of all the exercises this one had the most variability in terms of how participants could complete it. The same instructions were given to the participants in that they could chose the pattern in which task was completed (i.e. nuts were moved on the bolts) and that the number of nuts moved was not being recorded. The screwing/unscrewing was designed more to be a distraction during the test of upper extremity muscle endurance. As such, we found very low average vector magnitudes from the Actigraph placed on the waist. These ranged from raw data values of 0 - 19.44. Most participants found a comfortable stance and stayed in that position. In comparison, the average magnitudes for the wrist placement ranged from raw data values of 30.56 - 208.88. The range seen with the wrist placement can be attributed to the pattern chosen or the efficiency in movements. In regards to efficiency, it is of interest that although no significant correlations were found, both correlations were found to be negative. This would suggest that those with lower average vector magnitudes were able to complete the exercises for a longer period of time indicating that perhaps there was less overall movement of the upper extremity.

4.1.3 Relationship between Actigraph VMs and FCE six-minute walk test

The six-minute walk test is commonly used clinically and has been tested across a variety of populations. As such there is normative data from various studies and populations (36). This test is also a good measure of the body as a whole system (11). In our study, this test was conducted last and as such fatigue was expected to play a role in total distances walked. In some previous studies participants were told to walk as far as possible in 6 minutes (36) but during our study participants were told to walk for 6 minutes at a standard walking pace. This was done to best simulate real work activity as it is more important for workers to be able to maintain a steady pace than to push towards a maximal pace. No studies were found in which healthy adults

were tested with a similar mean age to our study, but Geiger et al. found similar trends in means but different trends in ranges for male and female participants aged 16-18 years. In both studies, males were found to have a higher mean total distance (m) but Geiger el al. found males to also have a larger range (37) whereas in our study males were found to have a smaller range than females.

In total we analyzed 16 different correlations during this study. Of the 16 correlations, the 6-minute walk test and total activity counts from the waist placement had the strongest correlation at r=0.66. We hypothesized a fair to moderate correlation (r=0.3-0.4), but found a stronger correlation. Although previous studies are limited when comparing these specific measures, one study was key in guiding our hypothesis. Barreira et al. found a high correlation (r=0.87) between step outputs from Actigraph GT3X accelerometer versus the YAMAX SW-200 pedometer in free-living adults placed on the waist (38). This Barreira el al. study considers that accuracy of steps as recorded by the Actigraph and not activity counts. During previous personal testing of the Actigraph however, it was noted that higher step counts result in higher activity counts.

A correlation of r=0.23 was found between total activity counts from wrist placement and distance, but was not found to be significant at $p<0.05$. This will be discussed further with ICC values.

4.1.4 ICC Agreement between waist and wrist Actigraph device placement

In our study we placed two Actigraph monitors on each participant. The first monitor was placed on the dominant side waist on the anterior superior iliac spine using a belt type strap. The second monitor was placed on the non dominant wrist with the Actigraph "box" on the top (anatomically posterior) side of the wrist. We were interested in how strong the agreement would be between the two device placements. Previous studies were found in which the placement of devices differed. Some equipped participants on the only the waist (17,22), the waist and low back (39), the waist and wrist (23,27) or the waist, wrist and ankle (21). Given the nature of our study we determined that the waist and wrist placement were the most practical for workers completing functional tasks. Many of the previous studies pre-determined which side of the body the monitor would be placed on, however we decided that we would base this on dominance. The dominant leg is generally the lead leg and as such we thought placement on the dominant hip

would provide the most accurate representation of center of mass motion. The wrist placement was also selected based on the weighted overhead exercises in which the non-dominant arm is generally the arm that will fatigue first and have a greater influence on duration of the exercise.

ICC was used to analyze level of agreement between both placements of devices in all 5 exercises. Previous studies have shown a higher output for wrist placement over waist placement (26,27) as such we were interested in the consistency of agreement and not absolute agreement. For the three lifting exercises, 6 ICC analyses were performed: 3 comparing waist and wrist peak VM and 3 comparing waist and wrist average VM. For the 2 remaining exercises 2 ICC analyses were performed comparing average VM for the overhead work tasks and total activity counts for the 6-minute walk test. Placements comparing peak VM were found to have weaker agreements than average VM on all three lifting studies. In total, only one case demonstrated good agreement, while fair agreement was found in three. In four cases a poor agreement was found.

These findings did not support with our hypotheses that a good agreement would be found across the lifting exercises and 6-minute walk test. We believe that the differences between placements may be explained via the way in which the exercises were individually completed. In each of the lifting exercises and the 6MWT it was much easier to standardize the motion of the participants' legs or center of mass then it was their arms. Motions such as rotating or shaking of the arms would have impacted the vector magnitudes recorded by increasing the totals and this could be one factor leading to low agreement. Even with the weighted box in hand, it was possible that participants may have slightly altered their arm motion through the 5 repetitions, as it is much less likely they would have altered their leg or center of mass motion. Additionally, with the demonstration and instructions these individual motion variations could not be eliminated. This may also explain why our strongest agreement was found between average VM and the front carry task. This exercise was a single repetition while the two other lifting exercises were 5 repetition sets. There would have been less likelihood in variation with the single repetition then within the 5 repetitions. The poor agreement found in the 6MWT came as a surprise but can likely be explained by variations in walking mechanics, specifically arm swinging. Generally during walking the arms swing contralaterally with the legs on a 1:1 ratio (40). However this is not always the case as mechanics can vary significantly between individuals. One specific participant was noted to be holding his hands behind his back while

walking. Other motions such as adjusting clothing, stretching, or even bringing the hands up to cover a cough or sneeze would also have increased VM readings on the wrist device and in turn resulted in a weaker agreement. We were correct in hypothesizing that a poor agreement would be found on the overhead work task. As previously stated this was due to the assumption that participants would be relatively motionless with their legs and center of mass while moving their wrists and arms to screw and unscrew the nuts. The device placed on the waist moved very little for the duration of the exercises, while the device placed on the wrist was more frequently in motion. This overhead exercise focused largely on the upper extremity and not on the full body.

In terms of clinical implications of our findings, with the rapid development of activity monitors and their widespread acceptance, it is important to determine if and how they should be introduced into clinical practice. Clinicians could have the chance to equip individuals with these devices both in the clinic during assessment or for daily/ work routines. This would allow clinicians to compare Actigraph recorded movement data during both of these scenarios to look for discrepancies in average or peak counts. Discrepancies might suggest sub-maximal performance during the FCE or alternatively, similar counts could suggest that the individual is providing maximal effort. Also, further research may lead to thresholds of activity monitor output indicating that the individual being assessed is ready to work. There is also the possibility of building a database of activity counts from tests such as the 6MWT that could be used as a test replacement through knowing what magnitude of activity counts correspond to what distance walked. However, research in this area is currently in its infancy and further development is needed (see future research section below).

4.2 Limitations

There are a few important limitations inherent to this study. First, our sample consisted of all healthy individuals. FCEs are tests generally conducted on injured workers and this limits the applicability of our research to the intended target of these evaluations. With a healthy population, we did not have to be concerned with pain or psychosocial factors influencing the result. Due to the exploratory nature of our research we believe this was a necessary first step. However, given the activity limitations that come with age and physical conditions, there is a

need to conduct future research with various population groups to further understand the association between Actigraph device outputs and functional performance.

Second, our sample was collected using convenience sampling on a University campus and as such the mean age of the sample is not reflective of the mean age in the workforce. Naturally, those around a university campus are of a younger age and many have yet to join the workforce. We did not limit our study to these age ranges, they were, however, the most readily available given our location.

With respect to the Actigraph measure of vector magnitudes, we based this on trying to assess full 3-dimensional motion. An alternate approach would have been to only consider X or Y-axis data which may have led to different results. For example the floor to waist level lift is relatively low in movement in the X and Z axis with the majority of movement being in the vertical or Y axis. However, because the raw data is available from the devices this could be analyzed in future studies.

Overall, our study utilized a cross-sectional design to collect all the necessary data required. Future research could incorporate a longitudinal component where activity monitoring during FCE is compared to activity monitoring during real-world work activities.

4.3 Future Research

To our knowledge this was the first study to examine the relationship between data collected from a wearable device and performance on work-related functional tests. Further research should be conducted with a refined design to improve the scope of this research. First, a wider age range should be studied to examine similar results across a sample more representative of the workforce. Second, future studies should look to incorporate workers with injuries, beginning with minor injuries and progressing toward more severe or chronic disabling injuries or conditions. Third, to fully understand the applicability of these devices, research should be conducted comparing the Actigraph data from clinical functional evaluations and activity performed in the workplace. These changes would increase the quality of future research while broadening the scope and applicability of our conclusions.

4.4 Conclusions

A significant correlation was observed between data from the G3TX tri-axial Actigraph device and performance on functional capacity evaluations. In general, the waist placement of the Actigraph device appears more optimal than the wrist placement due to higher correlations observed with waist placement. Furthermore, average vector magnitudes were found to have a stronger correlation than peak vector magnitudes. Additionally, agreement between device placement (waist and wrist) ranged from poor to good agreement, again with average vector magnitude having a stronger agreement than peak vector magnitudes in the lifting exercises. These findings have important implications for trying to introduce new technology, specifically wearable devices, into clinical settings. Relatively little research has been conducting on this topic in the past and further research is require before definitive statements regarding the utility of these devices in conjunction with FCE can be made.

References:

1. Morgan MV, Allison S, Duhon D. Heart rate changes in functional capacity evaluations in a workers' compensation population. Work. 2012;42(2):253-7.
2. Gross DP, Battié MC, Cassidy JD. The prognostic value of functional capacity evaluation in patients with chronic low back pain: part 1: timely return to work. Spine. 2004;29(8):914-9
3. Matheson LN, Isernhagen SJ, Hart DL. Relationships among lifting ability, grip force, and return to work. Physical Therapy. 2002;82(3):249-56.
4. Lemstra M, Olszynski WP, Enright W. The sensitivity and specificity of functional capacity evaluations in determining maximal effort: a randomized trial. Spine. 2004;29(9):953-9.
5. Kirsh B, McKee P. The needs and experiences of injured workers: a participatory research study. Work. 2003;21(3):221-31.
6. Program NWIDS. Nature of Injury Per Year. In: Canada AoWCBo, editor. 2015.
7. Program NWIDS. Injury by Part Of Body Per Year. In: Canada AoWCBo, editor. 2015.
8. Schultz IZ, Stowell AW, Feuerstein M, Gatchel RJ. Models of return to work for musculoskeletal disorders. Journal of occupational rehabilitation. 2007;17(2):327-52.
9. Pransky G, Gatchel R, Linton SJ, Loisel P. Improving return to work research. Journal of Occupational rehabilitation. 2005;15(4):453-7.
10. Loisel P, Buchbinder R, Hazard R, Keller R, Scheel I, van Tulder M, et al. Prevention of work disability due to musculoskeletal disorders: the challenge of implementing evidence. Journal of occupational rehabilitation. 2005;15(4):507-24.
11. Genovese E, Galper JS, Association AM. Guide to the evaluation of functional ability: how to request, interpret, and apply functional capacity evaluations: American Medical Association; 2009.
12. Gross DP, Battié MC. Factors influencing results of functional capacity evaluations in workers' compensation claimants with low back pain. Physical Therapy. 2005;85(4):315-22.
13. Ferguson SA, Gallagher S, Marras WS. Validity and reliability of sincerity test for dynamic trunk motions. Disability and rehabilitation. 2003;25(4-5):236-41.
14. Gross DP, Battié MC, Cassidy JD. The prognostic value of functional capacity evaluation in patients with chronic low back pain: part 1: timely return to work. Spine. 2004;29(8):914-9.

15. Matheson LN, Isernhagen SJ, Hart DL. Relationships among lifting ability, grip force, and return to work. Physical Therapy. 2002;82(3):249-56.
16. Kimura S, Ozasa S, Nomura K, Yoshioka K, Endo F. Estimation of muscle strength from actigraph data in Duchenne muscular dystrophy. Pediatrics international : official journal of the Japan Pediatric Society. 2014;56(5):748-52
17. Santos-Lozano A, Santin-Medeiros F, Cardon G, Torres-Luque G, Bailon R, Bergmeir C, et al. ActiGraph GT3X: validation and determination of physical activity intensity cut points. International journal of sports medicine. 2013;34(11):975-82.
18. Lee JM, Kim Y, Welk GJ. Validity of consumer-based physical activity monitors. Medicine and science in sports and exercise. 2014;46(9):1840-8.
19. John D, Freedson P. ActiGraph and Actical physical activity monitors: a peek under the hood. Medicine and science in sports and exercise. 2012;44(1 Suppl 1):S86-9.
20. Santos-Lozano A, Torres-Luque G, Marín PJ, Ruiz JR, Lucia A, Garatachea N. Intermonitor Variability of GT3X Accelerometer. International journal of sports medicine. 2012;33(12):994-9.
21. Stec MJ, Rawson ES. Estimation of resistance exercise energy expenditure using triaxial accelerometry. Journal of strength and conditioning research / National Strength & Conditioning Association. 2012;26(5):1413-22.
22. Rothney MP, Schaefer EV, Neumann MM, Choi L, Chen KY. Validity of physical activity intensity predictions by ActiGraph, Actical, and RT3 accelerometers. Obesity. 2008;16(8):1946-52
23. Chen KY, Acra SA, Majchrzak K, Donahue CL, Baker L, Clemens L, et al. Military metabolic monitoring. Predicting energy expenditure of physical activity using hip- and wrist-worn accelerometers. Diabetes Technology & Therapeutics. 2003;5(6):1023-33
24. Karantonis DM, Narayanan MR, Mathie M, Lovell NH, Celler BG. Implementation of a real-time human movement classifier using a triaxial accelerometer for ambulatory monitoring. IEEE Transactions On Information Technology In Biomedicine: A Publication Of The IEEE Engineering In Medicine And Biology Society. 2006;10(1):156-67.
25. Bonomi AG, Goris AHC, Bin Y, Westerterp KR. Detection of Type, Duration, and Intensity of Physical Activity Using an Accelerometer. Medicine & Science in Sports & Exercise. 2009;41(9):1770-7.

26. Hildebrand M, VT VANH, Hansen BH, Ekelund U. Age group comparability of raw accelerometer output from wrist- and hip-worn monitors. Medicine and science in sports and exercise. 2014;46(9):1816-24
27. Rosenberger ME, Haskell WL, Albinali F, Mota S, Nawyn J, Intille S. Estimating Activity and Sedentary Behavior From an Accelerometer on the Hip or Wrist. Medicine and science in sports and exercise. 2013;45(5):964-75.
28. Kuijer P, Gouttebarge V, Brouwer S, Reneman M, Frings-Dresen M. Are performance-based measures predictive of work participation in patients with musculoskeletal disorders? A systematic review. International archives of occupational and environmental health. 2012;85(2):109-23.
29. Bieniek S, Bethge M. The reliability of WorkWell Systems Functional Capacity Evaluation: a systematic review. BMC musculoskeletal disorders. 2014;15(1):106
30. Brouwer S, Reneman MF, Dijkstra PU, Groothoff JW, Schellekens JMH, Göeken LNH. Test–Retest Reliability of the Isernhagen Work Systems Functional Capacity Evaluation in Patients with Chronic Low Back Pain. Journal of occupational rehabilitation. 2003;13(4):207-18.
31. Bautmans I, Lambert M, Mets T. The six-minute walk test in community dwelling elderly: influence of health status. BMC geriatrics. 2004;4(1):6.
32. Li A, Yin J, Yu C, Tsang T, So H, Wong E, et al. The six-minute walk test in healthy children: reliability and validity. European Respiratory Journal. 2005;25(6):1057-60.
33. Baldwin ML, Butler RJ. Upper extremity disorders in the workplace: costs and outcomes beyond the first return to work. Journal of occupational rehabilitation. 2006;16(3):303-23.
34. Portney LG, Watkins MP. Validity of measurements. Foundations of clinical research: Applications to practice. 2000:69-86.
35. McDowell I. Measuring health: a guide to rating scales and questionnaires. Oxford University Press; 2006:10–54
36. Rehab Measures - 6 Minute Walk Test [Internet]. The Rehabilitation Measures Database. [cited 2016Mar4]. Retrieved from: http://www.rehabmeasures.org/lists/rehabmeasures/printview.aspx?id=895
37. Geiger R, Strasak A, Treml B, Gasser K, Kleinsasser A, Fischer V, et al. Six-Minute Walk Test in Children and Adolescents. The Journal of Pediatrics. 2007;150(4):395-9.e2.

38. Barreira TV, Tudor-Locke C, Champagne CM, Broyles ST, Johnson WD, Katzmarzyk PT. Comparison of GT3X Accelerometer and YAMAX Pedometer Steps/Day in a Free-Living Sample of Overweight and Obese Adults. JOURNAL OF PHYSICAL ACTIVITY & HEALTH. 2013;10(2):263-70.
39. Trost SG, McIver KL, Pate RR. Conducting Accelerometer-Based Activity Assessments in Field-Based Research. Medicine & Science in Sports & Exercise. 2005;37(Supplement):S531-S43.
40. Meyns P, Bruijn SM, Duysens J. The how and why of arm swing during human walking. Gait & Posture. 2013;38(4):555-62.
41. PAR-Q & You. Canadian Society for Exercise Physiology; 2012. http://www.csep.ca/cmfiles/publications/parq/par-q.pdf
42. Reneman MF, Fokkens AS, Dijkstra PU, Geertzen JHB, Groothoff JW. Testing lifting capacity: Validity of determining effort level by means of observation. Spine. 2005;30(2):E40-E6.
43. Matheson LN. Test Instructions and Administration. Epic Lift Capacity Examiner's Manual. 2003. p. 54–62.
44. Ustun TB. THE ICF: AN OVERVIEW. Centers for Disease Control and Prevention; https://www.cdc.gov/nchs/data/icd/icfoverview_finalforwho10sept.pdf

Appendices

Appendix A – Timelines of the project

Key Project Milestones	Start Date	Completion Date
Proposal Writing and modification	June 2105	Sept 2015
Proposal defense	Sept 2015	
Research conducting/data collection	Nov 2015	Feb 2016
Statistical analysis	Feb 2016	Feb 2016
Thesis writing and modification	March 2016	July 2016
Thesis defense	Fall semester of 2016	
Knowledge transfer	Sept 2016	Dec 2016

Appendix B – Budget considerations

This study will require some funding for salaries and operational costs. The University of Alberta provides $5,800 per semester to the primary researcher as a research assistantship to perform tasks such as background information gathering, data collection, statistical analysis and report writing. The University of Alberta Faculty of Rehabiliation Medicine will provide all software required (SPSS, Microsoft office, Actilife). The Actigraph devices are being borrowed from Mount Royal University in Calgary, Canada through Christy Lane. All study participants will be receiving a $40 stipend for their time. This cost will be funded by operational grants through Dr. Doug Gross. Due to funding and availability of equipment, budget will not limit this study.

Appendix C – research expertise

The following people will be involved with this study:

Jesse Karpman is a MSc student in the Faculty of Rehabilitation Medicine at the UofA. He completed his undergraduate degree in Science, majoring in biology with a minor in business. He

has previous publications in the field of concussion research as a research assistant. He is familiar with FCEs and Actigraph devices.

Dr. Douglas Gross has a Doctoral degree in Rehabilitation Science and is the interim chair of the Department of Physical Therapy at the UofA. He has clinical experience as a physiotherapist in both primary care and occupational rehabilitation centers. He has extensive research and publications on worker disability and FCEs. Dr. Gross will be supervising Jesse Karpman on this study.

Joanne Park has a Bachelor in Occupational Therapy from the UofA. She is currently working as an Occupational therapist at of WCB Millard Health. She will be involved in helping to write the scripts and training Jesse on how to administer the FCE exercises.

Appendix D – Recruitment Poster

Department of Physical Therapy
University of Alberta

PARTICIPANTS NEEDED FOR RESEARCH ON WEARABLE FITNESS DEVICES

We are looking for volunteers to take part in a study of
Performance-Based Tests of Work-Related Functional Capacity while Equipped with Wearable Fitness Devices

As a participant in this study, you would be asked to complete a series of 5 exercises. You will do these activities while wearing activity monitors (similar to a fitbit).

Your participation would involve 1 session of ~2 hours.

You will be reimbursed for your time.

For more information or to volunteer for this study, please contact:
Jesse Karpman, MSc Rehab Science

Appendix E – PAR-Q form

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME _____

SIGNATURE _____ DATE _____

SIGNATURE OF PARENT or GUARDIAN (for participants under the age of majority) _____ WITNESS _____

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

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Appendix F – Participant Information Sheet

Title: Do Wearable Fitness Devices Correlate With Performance-Based Tests of Work-Related Functional Capacity?

Principal Investigators: Dr. Doug Gross
Thesis Student: Jesse Karpman
E-mail: jkarpman@ualberta.ca

Background: Functional capacity evaluations (FCE) are tests that help doctors and therapists determine what physical activities people can safely do at work. We are conducting a study to compare data from wearable fitness monitors (similar to a Fitbit) and results from functional capacity evaluation. We are asking for you to participate in this study.

Purposes of this research

- To describe activity levels during 5 FCE items selected from a commonly used FCE protocol using wearable activity monitors.
- To determine the correlation between activity monitor and exercise results.

What is Involved: If you agree to participate in this study we will ask you to complete a series of 5 exercises selected from the WorkWell FCE protocol. You will do these activities while wearing 2 fitness monitors. One monitor will be on your wrist and the other on your hip. You will also be asked to put on a heart rate monitor that includes a strap around your chest. No other special preparation is needed, but you should bring exercise clothes and shoes. We will ask you to complete 5 exercises while wearing the fitness monitors. The first three exercises involve lifting where you will lift a weighted box from one position to another. The fourth exercise involves overhead work (using your hands) until fatigue. The last exercise is a walk test where you walk as far as you can in 6 minutes. The entire procedure should take less than 2 hours.

Risks: FCE testing involves maximum ability determination. This may lead to muscle soreness such as the soreness that often accompanies strenuous exercise. This will dissipate after 2-3 days following testing. You will be observed carefully during testing for safety and will have the ability to stop testing at any time. The only other potential risk is the loss of confidentiality for you. This risk is minor and all efforts will be made to keep your information confidential. The researchers will not disclose your name or any other information needed to initialize the Actigraph devices to any third party.

Benefits: There are no direct benefits to you for participating in this research. Research findings may benefit future patients following the results of this study through improving the clinical practice of FCE.

Confidentiality

By signing this consent form you are saying it is okay for the study team to collect, use and disclose information about you as described above. What you tell us will be kept confidential. When we report our study findings, we will not use your name or any other personal information. All study data will be stored in a locked facility on password-protected computers in Corbett Hall at the University of Alberta. It will be stored for a minimum of 5 years as required by university regulations.

Results will be presented in an untraceable format in any presentations and publications. People will not be able to identify you from the data.

Compensation: You will receive $40 to compensate for your time. If you choose to withdraw early you are still entitled to a portion of the total compensation.

Freedom to Withdraw: If you do not want to be in this study you do not have to. You are free to withdraw from the study at any time. If you decide to withdraw from the study and do not want us to use the information you have already given us, we will respect your wishes.

Contact Names and Telephone Numbers: If you have any questions about this study you can speak with Jesse Karpman by emailing jkarpman@ualberta.ca or contacting the study supervisor Dr. Doug Gross by phoning 780-492-2690. If you have any questions or concerns regarding this study or your rights as a research subject, please feel free to contact the UofA Research Ethics Office at 780-492-2615.

Appendix G – Step-by-Step Exercise Instructions

Lifting + Carry

This is a test that will help us determine how much weight you can lift on a safe dependable basis.

We will do this test in three parts. The first exercise is the floor to waist lift. I want you to pull the box nice and close towards you, turn, squat, come back up, turn and place it back on the shelf. I want you to do that 5 times. **DEMONSTRATE**. After you have completed your set, I will ask for your heart rate and if you think you can lift with increased weight. If it is okay with you, we'll keep going. If you feel like that is the maximum amount of weight you can lift then we will move on to the next exercise.

Now, do you have any questions?

(they will do exercise)

(finished) – okay, what is your heart rate? Do you think you can handle more weight?

(if yes) Okay, I will add more weight to the crate. Please have a seat and try to limit your movements while I do this. Remember it will be heavier, so if you need to stop you may do so at any time.

(rest period between sets – HR under 100 or 2 min)

The second exercises is the waist to crown level lift. I want you to pull the box in nice and close, take a step back, lift the box up and walk it forward, placing it on the upper shelf then bring it back down and walk it forward onto the lower shelf. **Demonstrate**. Again, after you have completed your set, I will ask for your heart rate and if you think you can lift with increased weight. If it is okay with you, we'll keep going. If you feel like that is the maximum amount of weight you can lift then we will move on to the next exercise.

Now, do you have any questions?

(they will do exercise)

(finished) – okay, what is your heart rate? Do you think you can handle more weight?

(if yes) Okay, I will add more weight to the crate. Please have a seat and try to limit your movements while I do this. Remember it will be heavier, so if you need to stop you may do so at any time.

(rest period between sets – HR under 100 or 2 min)

The third exercise is a horizontal carry. Unlike the previous exercises this is only 1 repetition. I want you to pull the box nice and close to you, turn and then follow the markings on the floor to walk to the end, turn and walk back, finishing by placing the box back on the shelf. **Demonstrate**. Again, after you have completed your set, I will ask for your heart rate and if you think you can carry with more weight. If it is okay with you, we'll keep going. If you feel like that is the maximum amount of weight you can lift then we will move on to the next exercise.

Now, do you have any questions?

(they will do exercise)

(finished) – okay, what is your heart rate? Do you think you can handle more weight?

(if yes) Okay, I will add more weight to the crate. Please try to limit your movements while I do this. Remember it will be heavier, so if you need to stop you may do so at any time.

(rest period between sets – HR under 100 or 2 min)

<u>Overhead work</u>

The object of this test is to complete an overhead task for as long as you can tolerate. What I want you to do is remove and replace these nuts onto the bolts. **Demonstrate.** Weights will be strapped on each wrist during the exercises. Time will run until you can no longer continue to complete the task.

Now, do you have any questions?

(they will do exercise)

(finished) – okay, what is your heart rate?

<u>6MWT</u>

The object of this test is to walk as far as possible for 6 minutes. You will walk back and forth in this hallway. Six minutes is a long time to walk, so you may get out of breath or become tired. You are permitted to slow down, to stop, and to rest as necessary. If you stop, I want you to continue to walk again as soon as possible. You will be walking back and forth between the markers. You should pivot at each end point and continue back the other way. Now I'm going to show you.

(Demonstrate)

Are you ready to do that? I am going to keep track of the number of laps you complete. I will mark it each time you turn around at this starting line. Remember that the object is to walk as long a distance as possible for 6 minutes, but don't run or jog. Are you ready to begin?